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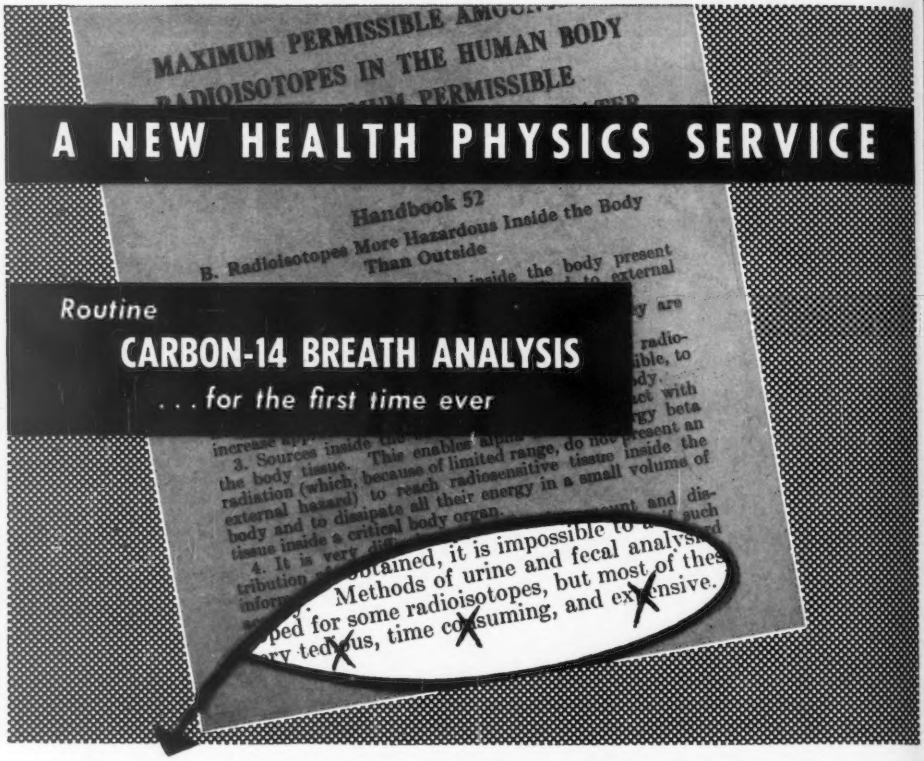
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B. Radioisotopes More Hazardous Inside the Body Than Outside
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The Pulmonary Reaction to Sheet Fiberglas-Plastic Dust*

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Haskell Laboratory for Toxicology and Industrial Medicine, E. I. du Pont de Nemours & Company, Wilmington, Delaware

THE SHEET Fiberglas-plastic† whose biological action in experimental animals will be described was almost identical (except for the filler) to the molded Fiberglas-plastic whose pathogenicity was reported elsewhere.[1] In sheet Fiberglas-plastic the filler is pulverized calcium sulphate and this substance has not previously been shown to elicit adverse tissue changes even after prolonged inhalation, and may limit the effect of crystalline free silica dust simultaneously deposited in the pulmonary tissues.[2, 3] Calcium carbonate dust, which is the filler for molded Fiberglas-plastic, is also inert when inhaled.[4] The study of the effects of the calcium carbonate filled Fiberglas-plastic dust on rats, guinea pigs and rabbits suggested that this substance is classifiable with the group of inert industrial products. The present report will indicate what effect the substitution of $CaSO_4$ filler for the $CaCO_3$ filler had in experimental animals.

Materials and Methods

The dust was used without modification having been collected in a section of the plant where sheet Fiberglas-plastic is sawed or burnished. The animals were exposed by inhalation in a manner identical to that described in the experiment with the $CaCO_3$ filled Fiberglas-plastic.[1] These two studies matched each other except for their duration. The inhalation phase of the inquiry with the $CaSO_4$ filled Fiberglas-plastic dust was terminated after approximately ten months of exposure while the $CaCO_3$ study was continued for 25 months. The numbers of animals used for each phase of the study are in Tables I and II. The average dust level of 283 million particles per cubic foot of air (Figure 1) was somewhat lower than the dust level of 338 million particles per cubic foot of air maintained in the experiment with the $CaCO_3$ filled Fiberglas-plastic. The initial average monthly exposures were, however, significantly higher than were those achieved in the first experiment. Levels ranging from about 300 to 450 million particles per cubic foot of air were maintained during the initial five months. Thereafter, the exposure was reduced to a range between 110 and 240 million particles per cubic foot of air.

Mortality Trends

Of the control guinea pigs not exposed to dust five per cent succumbed to intercurrent disease. None of the guinea pigs exposed to the sheet Fiberglas-plastic dust died spontaneously during the period of study. This is significant as an index of the relative inertness of the dust.

Among the rats, spontaneous deaths accounted for more than half of the animals. During the same period, however, half of the control rats also died from an intercurrent epizoötic infection. There is, therefore, no statistical indication that the inhaled sheet Fiberglas-plastic dust significantly influenced the mortality rate in rats.

Of the rabbits, 17 per cent died during the period of dust exposure. Alarming though this may seem, the fact that 40 per cent of the control unexposed rabbits perished over a period of three years, mainly from pulmonary causes, negates the suggestion that the inhaled dust from sheet Fiberglas-plastic may have been a factor in the deaths of the exposed animals.

The seven per cent death rate in the guinea pigs infected with R1 tuberculosis and thereafter continuously exposed to the sheet Fiberglas-plastic dust (Table II) represents a single animal which was ill and was killed. There were no deaths among the reactivation study group of animals. The normal controls not exposed to dust or infected with tuberculosis yielded a death rate of five per cent, while all the infected control guinea pigs exposed to quartz dust died from tuberculosis.

Studies on Uninfected Guinea Pigs

EXPOSURE PHASE

The tissue response falls within the inert category. The maximal reaction occurred during the

* The experimental phase of the study was carried out at the Saranac Laboratory, Saranac Lake, New York. Equipment was loaned by the Office of Naval Research, Washington, under Contract Nonr 1871 (01).

† For brevity the calcium sulphate-filled Fiberglas reinforced polyester resin sheet plastic is referred to simply as sheet Fiberglas-plastic.

TABLE I

The Biological Action of Inhaled Sheet Fiberglas-Plastic Dust

Summary of component studies on uninfected animals

Animals		Phase of experiment	Duration of exposure months		Spontaneous deaths per cent
Type	Number		Fiberglas plastic dust	Normal air	
Guinea pigs	4	Pilot exposure	0.2	—	0
	20	Continuous exposure	2-9.3	—	0
	40	Elimination	9	6	0
	100	Control	0	0.2-36	5
Rats	20	Continuous exposure	3-9.3	—	55
	100	Control	0	0.5-24	50
Rabbits	6	Continuous exposure	9.3	—	17
	3	Elimination	9	3- 6	0
	50	Control	0	1-36	40

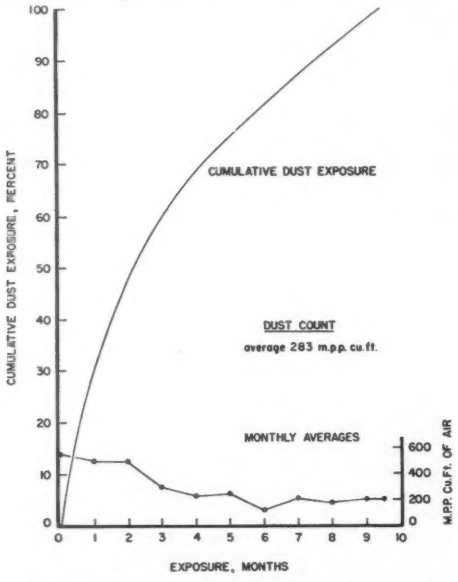

FIGURE 1. The graphs demonstrate the monthly variations in the dust counts in an inhalation experiment with sheet Fiberglas-plastic dust. The cumulative potential exposure to which the animals were subjected is also recorded. The dust counts were made by the standard light field method.

first two months but even the transient changes were of a nonspecific character.

The weight of the lungs usually increases markedly in animals exposed to hazardous dusts.[1] In the present experiment the lung weights did not significantly exceed the normal range during the first eight months. Thereafter, there was a sharp increase (Figure 2). After cessation of dust exposure the lung weight decreased.

A noteworthy histological feature in the lungs of animals killed at the end of two months consisted of focal hyperemia with isolated minute petechiae. This hyperemia was limited to periductal distension of alveolar mural capillaries, and the petechiae occurred in relation to these dilated capillaries. At multiple points throughout the lung parenchyma small accumulations of agranular and dust-filled macrophages were found. The latter predominated. At a number of points there also was focal infiltration of the alveolar walls by agranular macrophages. A minor grade of diffuse dilatation of alveoli and focal distension of alveolar ducts accompanied the foregoing changes. The bronchioles and bronchi displayed some catarrhal inflammation with focal loss of epithelium. Among the desquamated cells eosinophils were present in moderate numbers. Negligible hyperplasia of the pulmonary lymphatics was discernible without corresponding reaction in the hilar lymph nodes.

During subsequent phases when animals were killed at the end of 4, 5, 8, and 9.3 months of residence in the dust, all the foregoing responses regressed at variable rates. Focal hyperemia was not seen after the second month and the pete-

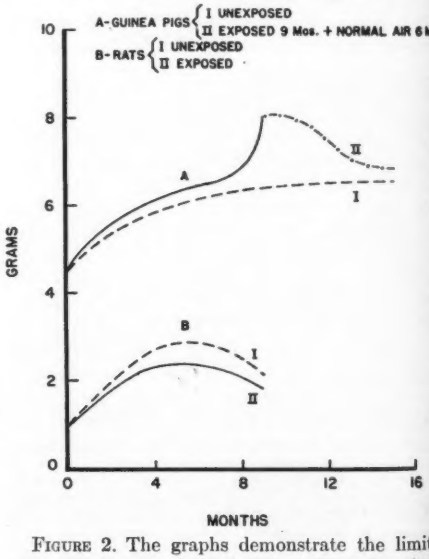

FIGURE 2. The graphs demonstrate the limited over-all influence of inhaled sheet Fiberglas-plastic dust on the lung weights of experimental animals.

chiae disappeared. The swollen alveolar macrophages diminished progressively and after the end of nine months of exposure isolated phagocytes only were present in some of the peripheral alveoli and alveolar walls. Alveolar space and duct distension was not observed after the second month of exposure. Minor bronchiolar and bronchial catarrhal inflammation persisted as a sporadic feature in all the animals, but the slight degree of eosinophil infiltration of the bronchiolar mucosa disappeared after the fourth month of exposure. Hyperplasia of the pulmonary lymphatics diminished progressively. At the sixth month isolated hilar lymph nodes contained a few dust-filled multinucleated giant cells. There was, however, no progressive increase in the transference of dust-filled cells to the lymph nodes, and in the animals killed after more than nine months of dust exposure there was less dust in the lymph nodes than in those animals killed at the end of six months. Hyperplasia of the cortical lymphoid follicles occurred sporadically, but no phagocytes were identified in the follicles.

Organs other than the lungs were not affected to any material degree. The hepatic portal lymph nodes showed a minor grade of dilatation of sinuses which were filled with macrophages. In some of the animals killed at the end of six and eight months in the dust, a few of the centrilobular liver cells were vacuolated, but this change was not in excess of that which occurred sporadically in the control guinea pigs not exposed to dust. The pancreas was somewhat hypotrophic and there was no hyperplasia of the islet cells. In the spleen there was minimal accumulation of dark pigment which seemed to increase slightly with the passage of time. None of the other organs displayed tissue reaction to the inhaled dust.

ELIMINATION PHASE

After 9.3 months' dust exposure the guinea pigs which had not yet been killed for sampling were taken out of the dust room and the effect of residence in normal air on the course of the pulmonary reaction was studied. After the third day in normal air the focal mural cellular infiltrations which developed during the dust exposure became more sharply defined, particularly in the bases of the different lung lobes. There was enhanced desquamation of bronchial epithelial cells but eosinophils were no longer observed in the detritus. The slight hyperplasia of the medulla and cortex of the lymph nodes receded but a few phagocytes persisted in the medulla.

Focal hyperemia became a prominent feature

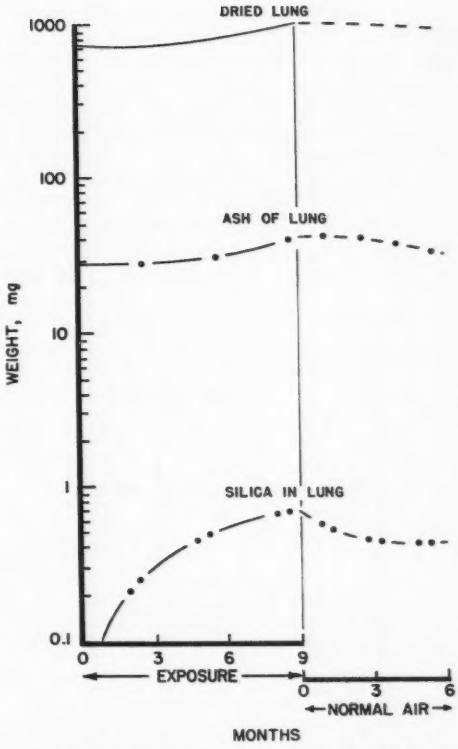

FIGURE 3. The graphs demonstrate the relatively slow rate of accumulation of silica in the lungs of guinea pigs exposed by inhalation to the sheet Fiberglas-plastic dust. During the corresponding period the increase in the weight of the dried lung and of the lung ash was insignificant. On cessation of the dust exposure, the lung weight and ash content of the lung returned to about the starting levels. After two months there was no further elimination of silica. The ordinates have been plotted on a logarithmic scale for ease of reference.

in the animals killed after seven days in normal air. By the end of a month focal hyperemia was marked and almost universal in distribution. During the succeeding four months this reaction declined rapidly. There were transient petechiae in the hyperemic areas during the first two months after the animals were transferred to normal air.

The focal infiltration of the alveolar walls increased transiently until the end of the first month in normal air. At the end of six months the alveolar walls were normal in appearance and at no stage was fibrosis detectable. Distension of alveolar spaces persisted sporadically but

in the majority of the animals became progressively less evident. Alveolar mural infiltration ran a parallel regressive course. The bronchial and bronchiolar reactions decreased progressively and by the end of the sixth month of residence in normal air no abnormalities were demonstrable.

CHEMICAL ANALYSIS

The minimal tissue responses were matched by very low levels of retained silica (Figures 3 and 4). The maximal SiO_2 retention after nine months of continuous exposure to the sheet Fiberglas-plastic dust was only 0.9 mg, yielding a ratio of SiO_2 to dried lung weight of 0.08 per cent. At the corresponding stage during the experiment with the calcium carbonate filled Fiberglas-plastic product[3], the SiO_2 level was between 2.2 and 2.45 mg, yielding a ratio of SiO_2 to dried lung weight of approximately 0.19 per cent. As the dust exposure in the experiment with the calcium sulphate filled Fiberglas-plastic dust initially was appreciably higher than levels at the comparable stage in the experiment with the calcium carbonate filled product, it would seem that the presence of the calcium sulphate may have counteracted the accumulation of silica in the guinea pig lung.

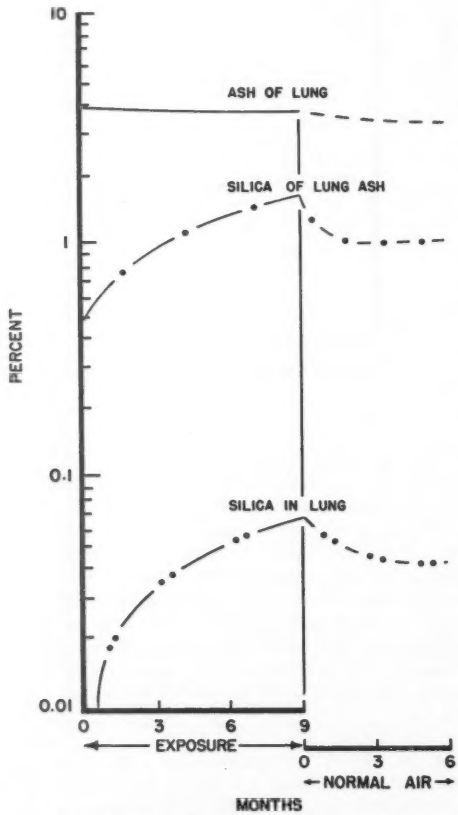

FIGURE 4. When the gravimetric values for the silica in the lung, the lung ash, and the dried weight of the lung of guinea pigs exposed by inhalation to sheet Fiberglas-plastic dust are expressed as percentages of one another, the moderately pronounced rate of retention of silica in the lung is contrasted with the lack of increase in the ash level of the dried lung. The ratios demonstrate that although the silica is progressively retained in the lung, there is no corresponding tissue response.

Analysis of the lungs of the animals which had been transferred to normal air further confirmed the retarding influence of calcium sulphate on the pulmonary retention of SiO_2. The SiO_2 levels dropped by 44 per cent to approximately 0.5 mg per animal at the end of two months after the guinea pigs had been removed from the dust environment. By comparison, in the experiment with the molded Fiberglas-plastic containing calcium carbonate, 2.4 mg SiO_2 was still present in the lungs at the end of three months residence in normal air, i.e., a reduction of only 22 per cent. However, in the latter case the dust exposure had been continued for 24 months before the animals were transferred to normal air.

Studies on Rats

At autopsy there were minimal signs only of reaction to the dust. The lung weights had not increased materially. Indeed, the lungs weighed less than those of normal rats of corresponding age (Figure 2). This contrasts rather sharply with the weight gains which are usually encountered when there is an underlying pneumoconiosis. No dust reaction was noted macroscopically. The tracheobronchial lymph nodes were enlarged in two animals only. There was no detectable change in the hepatic portal lymph nodes. No pathologic changes were observed in other extrathoracic organs.

On microscopic examination it was apparent that there was an initial reaction which subsequently diminished during continued dust exposure. In the animals killed at the end of three months there were moderate numbers of dust-filled macrophages in the alveolar spaces and alveolar walls. Minor emphysema was noted in one animal. The alveolar ducts were slightly dilated in all the rats and at isolated foci phagocytes had congregated in periductal alveolar spaces and in paraductal lymphoid deposits.

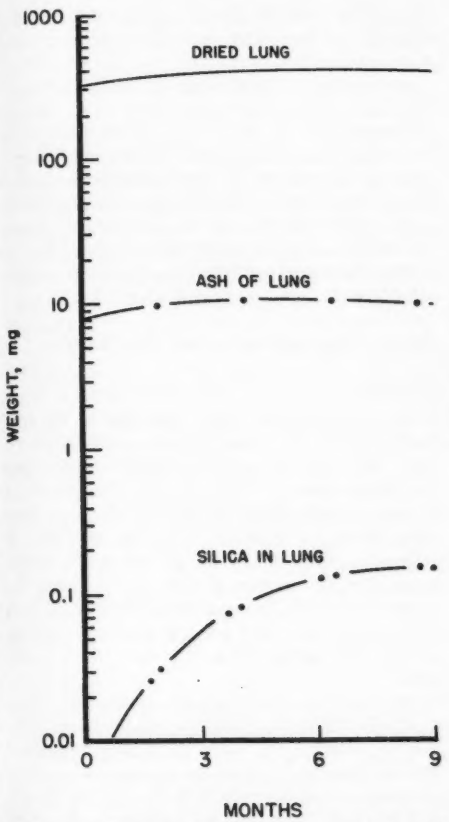

FIGURE 5. The graphs demonstrate the limited retention of silica in the lungs of rats exposed by inhalation to the sheet Fiberglas-plastic dust. The weight of the dried lung and of the lung ash increased insignificantly.

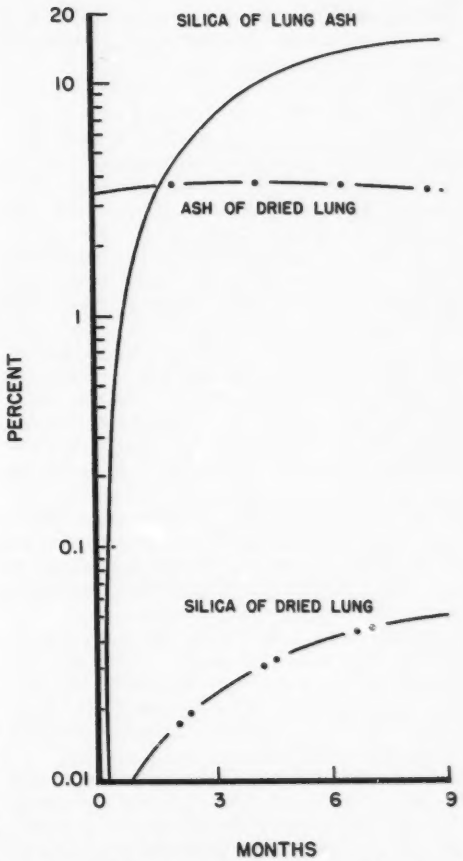

FIGURE 6. The moderately pronounced rate of retention of silica in the lung of rats exposed to sheet Fiberglas-plastic dust is contrasted with the lack of increase in the ash level of the dried lung. The ratios demonstrate that although the silica is progressively retained in the lung, there is no corresponding tissue response.

There were no microscopic changes in the hilar lymph nodes.

In the animals killed at the end of six months and nine months, respectively, the macrophages became progressively less evident both in the alveolar spaces and in the alveolar walls, slight emphysema was present in one animal and the periductal collections of dust-filled cells were slightly prominent in two animals. In the hilar lymph nodes minimal focal accumulations of koniophores were now seen.

No deviations of a pathological nature could be discovered in any of the other organs.

In the animals that died spontaneously superimposed inflammatory changes and slight postmortem autolysis were the only microscopic features. There were no pneumoconiotic reactions comparable to those seen in animals that were killed for study, nor were there any changes in the extrapulmonary organs which could not be accounted for on the basis of the superimposed infective changes.

Chemical analysis of the lungs of the rats (Figures 5 and 6) once more demonstrated the low levels of retained silica. The maximal values for SiO_2 did not exceed 0.17 mg (or 0.05 per cent of the weight of the dried lung). At a comparable stage in the experiment with the calcium carbonate filled Fiberglas-plastic, more than six times this amount of SiO_2 had accumulated in the lungs

of the rats. The lung ash and dried lung weights varied little from those of normal unexposed rats.

Studies on Rabbits

In the rabbit which had died a month and a half after the start of the experiment there was a bronchopneumonia similar to that which caused the deaths among the control rabbits not exposed to any dust (Table I).

At the time of necropsy only one of the rabbits which were killed for study showed macroscopically detectable reaction to the inhaled dust. This change was limited to slight green-grey subpleural pigmentation forming a linear pattern posteriorly and laterally. The histologic reaction to the inhaled dust was limited. In the animal killed at the end of the third month the only perceptible deviation from the normal was diffuse alveolar wall hyperemia with moderate numbers of macrophages in the alveoli. In a few periductal alveoli some of these macrophages were clustered together. There were no changes in the lymph nodes, the bronchial passages, or the blood vessels. No adverse effects were discerned in the extrathoracic organs.

In the rabbit killed at the end of six months there was no additional change. Indeed this rabbit showed somewhat less reaction to the dust in that there no longer was demonstrable hyperemia and the alveolar macrophages were few in number.

In the four rabbits sacrificed at the end of nine months of exposure there was focal hyperemia in one instance only. The alveolar macrophages now were slightly more prevalent and many of these cells contained dust particles. Periductal clusters of macrophages were moderately well established and in these locations many of the phagocytes had been transformed into multinucleated koniophores.

In the rabbit killed three months after transference to normal air there were no pulmonary abnormalities. In the case of the animal which was killed six months after transference to normal air, there were no macrophages in most of the alveolar spaces, but in the periductal zones and subpleurally there still were a few minute koniophore clusters mixed with macrophages. No other changes were present in the lungs and the hilar lymph nodes were not affected.

TABLE II

The Influence of Inhaled Sheet Fiberglas-Plastic Dust on Experimentally Induced Pulmonary Tuberculosis
Summary of component studies

Dust exposure	Infection phase	Duration of study months	Number of guinea pigs	Spontaneous deaths per cent
Fiberglas plastic	Uninfected	2–9	64	0
	Simultaneous	2–10	15	7
	Reactivation	4–10	27	0
Quartz dust	Uninfected	2–24	50	50
	Simultaneous	2–20	25	100
	Reactivation	4–18	26	100
Control (no dust)	Uninfected	2–24	100	5
	Infected	2–10	15	0

Guinea Pigs Infected with Tuberculosis

CONTROL

The methods used were identical to those already described.[1] However, the present experiment was conducted at a period during which the stock culture of R_1R_V tubercle bacilli was in a phase of reduced virulence. All infections, however, induced a positive tuberculin reaction, the response being strong in all but seven guinea pigs. Toward the end of the eighth month the lesions had already undergone resolution. The experiment was, therefore, terminated approximately ten months from the date of the infection.

The numbers of tubercles discovered in the tracheobronchial and hepatic lymph nodes of the control guinea pigs were only about one-sixth the number that would ordinarily be expected in disease caused by the R_1R_V bacillus at its normal level of virulence. All lesions found at the end of the fourth month were showing signs of resolution. The tracheobronchial lymph nodes were moderately to markedly enlarged and indurated, but in one animal killed at the end of the fourth month these nodes were excessively large. The hepatic lymph nodes were slightly enlarged and their consistency was slightly increased. In animals killed after ten months no lesions were observed macroscopically in the hepatic lymph nodes.

Microscopic examination of the lungs confirmed the abortive nature of the tuberculosis. Tubercles rarely were found after the end of the sixth month and in only one of these, ten months from the date of infection, was scar tissue present.

In the tracheobronchial lymph nodes the tuberculous reaction was somewhat more advanced. Tubercles initially occurred both in the medulla and in the follicles and displayed a tendency to marginal confluence and central necrosis. Caseation, however, did not supervene. Confluence

and necrosis were no longer present six months after infection, and the majority of the tubercles had undergone resolution without scar formation. Slight periadenitis was demonstrated in two instances.

SIMULTANEOUS PHASE

On gross examination of the infected and exposed animals, the numbers of tubercles discovered at various stages were not materially in excess of those seen in the control series. However, tubercles survived slightly longer and were somewhat larger. They continued to have an efflorescent character until the end of the fourth month.

The tracheobronchial lymph nodes became markedly enlarged and very firm. After the end of the fourth month, these nodes decreased in size and consistency. The hepatic lymph nodes were somewhat hypertrophied and indurated during the first four months.

Histologically, several well-established tubercles were demonstrated in animals killed at the end of two months. Caseation was present in one instance. At later stages, necrosis was no longer evident and the lesions consisted of proliferating epithelioid cells. There was no subsequent fibrosis, calcification, or cavitation.

The range of influence of the simultaneous exposure of the guinea pigs to the sheet Fiberglas-plastic dust on the infection with R_1R_v tuberculosis are summarized in Figure 7. The dust exposure evidently furnished a slight stimulus to the course of the tuberculosis. In spite of the extremely low virulence of the infection, this stimulating effect cannot be wholly ignored. However, the impression is gained that the dust would not be capable of spreading a tuberculous infection to a disastrous degree. The infection died out almost as rapidly in the animals which were exposed to the dust as it did in those of

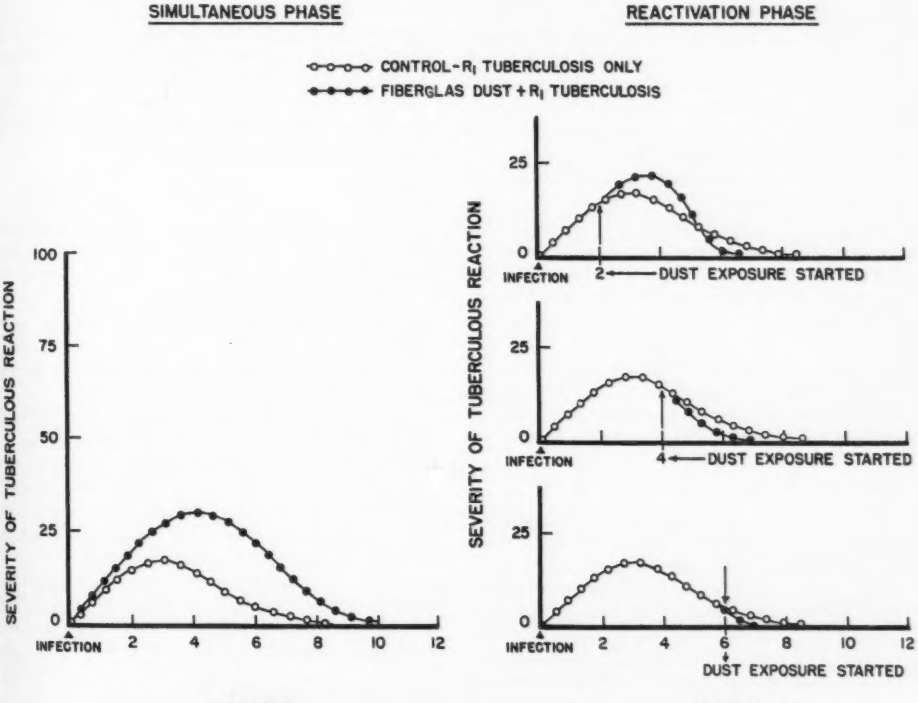

FIGURE 7. The graphs demonstrate the limited stimulation of the tuberculous process in guinea pigs during simultaneous phase and the almost total lack of reactivation of the tuberculosis in the reactivation phase. The pneumoconiotic response was entirely suppressed. Guinea pigs infected with R1 tuberculosis were exposed to dust of sheet Fiberglas-plastic after lapse of variable intervals.

the control series not exposed to the dust. There was no significant indication of aggravation of the specific reaction of the guinea pig lung to the inhaled dust.

REACTIVATION PHASE

The reactivation phase experiment in which the animals were placed in the dust chamber for variable periods after infection with R_1R_V tubercle bacilli was terminated at the end of about 10 months. The tuberculous response was minimal and the majority of the lesions were considerably smaller than those of the control series. Enlargement of the tracheobronchial lymph nodes, however, reached a marked degree in a few animals.

On microscopic examination, the lungs displayed virtually complete absence of mature tubercles. In most cases isolated focal mural infiltrations and isolated foci of hyperemia only were found and these lesions probably represented the response of the pulmonary tissue to the inhaled dust rather than to the tuberculous infection.

The changes evoked in the pulmonary lymph nodes also were more limited than those found in the control animals. Tubercles were found in only two animals. In both these cases, however, there was associated periadenitis.

No tubercles were discovered in the hepatic lymph nodes, spleen, liver, or kidney.

This phase of the experiment suggested that the inhaled dust decreased the normal intensity of the tuberculous infection. This inhibition was the more effective the longer the interval between the date of infection and the time the animals were placed in the dust room. There also were no parenchymal reactions in the lung tissue ascribable to the inhaled dust. This permits the inference that the prior tuberculous infection protected the lung tissue against the dust.

Comment

The Fiberglas-plastic industry is relatively new. Though reasonable hygiene steps to minimize the risk of dust exposure are being taken by responsible manufacturers, numerous phases of the creation and the use of the final product furnish opportunities for the accidental inhalation of particulates. It is for this reason encouraging to find that neither the calcium carbonate nor the calcium sulphate filled Fiberglas-plastics have the capacity to induce progressive pulmonary fibrosis in rats, guinea pigs, or rabbits.

Of the two products the calcium sulphate-filled type has the lesser capacity either to evoke pulmonary cellular responses or to modify the course of experimentally induced tuberculosis. This inference must be tempered with the reservation that the comparison is valid for the first nine to ten months of the experiment only. Furthermore, the intensity of the exposure during the first five months of the experiment with the calcium sulphate product was appreciably higher than the exposures during the corresponding phase of the calcium carbonate filled Fiberglas-plastic experiment.

The explanation for these differential effects may simply reside in the specific influences of calcium sulphate and calcium carbonate on the lung. Calcium sulphate exerts a selective protective action on the epithelial cells of experimental animals while suppressing the proliferation of lymphoid tissue. As progressive nodular pneumoconiotic lesions and tubercle formation only result if the reticulo-endothelial components of the lung retain the capacity to store, to transport, and to react to retained dust, the admixture of calcium sulphate with a nocuous particulate substance should reduce the pathogenicity of the latter. This point has already been demonstrated for mixtures of calcium sulphate and quartz.[2, 3] A comparable result may, therefore, be expected when calcium sulphate is mixed with other potentially deleterious substances.

Summary

1. The effect on pulmonary tissues of inhaled particulate sheet Fiberglas-plastic with a calcium sulphate filler is reported.

2. Judging by the responses in three animal species, the dust behaves as a biologically inert substance.

3. This lack of tissue response may be partly due to the low level of silica retention.

4. The sheet Fiberglas-plastic dust did not significantly influence the course of tuberculosis experimentally induced in guinea pigs. The tuberculous process decreased further the limited tissue responses to the inhaled dust.

5. Comparison with results obtained through a study of a similar commercial product with a calcium carbonate filler indicates that substitution of calcium sulphate as a filler may decrease the biological responses to inhaled dust of sheet Fiberglas-plastic.

Acknowledgement

Technical phases of this study were conducted by the following: A. J. Redlin performed the silica determinations, J. W. Jacobsen made the dust counts and A. B. Delahant was responsible for the necropsies.

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Invitation to Present Papers

THE 13TH INTERNATIONAL CONGRESS on Occupational Health will be held in New York City at the Waldorf Astoria Hotel, July 25–29, 1960. The Scientific Program Committee invites submission of papers for presentation at the Congress. The program will be devoted to the discussion of the following aspects of Occupational Health: (1) Administrative Practices, (2) Medical Practices, (3) Surgical Practices, (4) Education and Training, (5) Social and Legal Aspects, (6) Environmental Hygiene, (7) Influence of Environmental Factors on Health, (8) Work Physiology and Psychology, (9) Specific Industries, and (10) General. Those desiring to present papers must submit abstracts before January 1, 1960, to Dr. Irving R. Tabershaw, Chairman, Scientific Program Committee, International Congress on Occupational Health, 375 Park Avenue, New York, New York.

Abstracts should be typed double-space and contain not more than 200 words. Three copies in English are required and one copy in one of the other official languages (French, German, and Spanish). Include names, academic degrees, titles, and complete addresses of authors. The author who will present the paper should be listed first.

Original contributions rather than reviews of previously published materials will be given priority. Selection of papers will also be based on areas of interest and program space allotted to each section. Authors will be notified before March 1, 1960, of the Committee's decision.

Complete texts of accepted papers in any one of the official languages of the Congress must be submitted not later than April 1, 1960. Presentation may be in any of the official languages and will be limited strictly to fifteen minutes including slides. Printed abstracts will be distributed at the meeting and the complete papers will be published in the *Proceedings* following the meeting.

Health Hazards Associated with Rolling Normal and Enriched Uranium–Evaluation and Control*

EDWIN C. HYATT

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Introduction

THE PURPOSE of this paper is to present sufficient information to help industries planning to roll uranium to understand fully the nature and degree of the health hazards associated with the process and the basic control measures required for safe operation. It should be emphasized that exposures are held to a minimum because of adequately planned control measures, and not that uranium rolling does not present health hazards.

During the past five years, all the rolling experiments conducted at the Los Alamos Scientific Laboratory (LASL) and at off-site plants have been performed by supervisory and operating personnel who are fully informed regarding the nature and degree of hazards produced by their work. In applying control measures and evaluating exposures during rolling operations, the Health Division of LASL has received the full co-operation of all personnel involved.

Industrial health surveys have been made to evaluate potential health hazards due to (1) inhalation of uranium oxide, (2) external radiation and (3) surface contamination. This paper is concerned with the problems of inhalation and external radiation; the evaluation and control of surface contamination are discussed separately by Charles D. Blackwell.[1]

METHODS OF ROLLING

The uranium stock for rolling is cast into a hollow cylinder and cut into segments approximately 8 x 9 inches. The surface is usually prepared for rolling by machining. The details of preparation and various rolling methods are described by Hanks, et al.[2] The preheating and subsequent reheating of cast ingots and plates during hot breakdown rolling (600–625°C) was accomplished in a salt bath (potassium carbonate 65% and lithium carbonate 35%). Uranium is rolled to finish gage by "warm rolling" after heating in an oil bath up to 340°C.

The results reported in this paper were obtained during hot and warm rolling at LASL and at two off-site plants. The hot rolling at LASL was done on a Bliss Two-Hi rolling mill (Figure 1). A Three-Hi hot breakdown mill was used at the Haynes-Stellite Company, Kokomo, Indiana, to roll plates larger than could be accommodated on the Los Alamos equipment. The warm rolling was done at LASL on a Loewy Four-Hi mill equipped with slot-type local exhaust hoods. Additional warm rolling to obtain 0.40-inch sheet was done on a 12-roll Sendzimer mill at the Rodney Metals Company. For this work, the sheet was warmed with banks of infrared heat lamps.

Uranium Radiation Hazards

The potential radiation hazards arising from rolling uranium are those from inhalation of uranium oxide dust and external radiation. The internal hazard constitutes the greatest health problem when processing uranium metal. The most important source of dust is from the uranium oxide dust formed during heating of the billets and sheets.

INTERNAL RADIATION HAZARDS

The maximum allowable concentration of normal uranium dust at LASL is 50 micrograms per cubic meter of air ($\mu g/M^3$), or 70.0 disintegrations per minute per cubic meter ($d/m/M^3$). The control measures required for the dust can be compared with those for other metals, such as cadmium, selenium and tellurium, which have maximum allowable concentrations of 100 $\mu g/M^3$.

Handling of enriched uranium presents a much greater problem than does the handling of normal uranium, but only because of its greater alpha activity. A microgram of enriched uranium emits from 100 to 200 times more alpha radioactivity than does one microgram of normal uranium. The maximum allowable concentration

* This study was performed under the auspices of the U.S. Atomic Energy Commission.

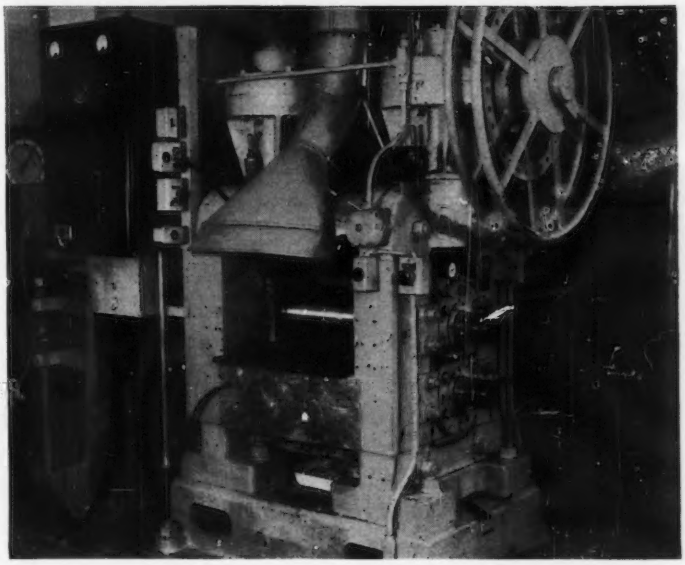

FIGURE 1. A rear view of the LASL Two-Hi Bliss hot rolls equipped with slot-type local exhaust hoods at front and rear of rolls. The 8-inch main exhaust duct draws 1500 cfm through the two slots, which have 21- and 4- inch openings.

is 70.0 d/m/M³, but this is equivalent to approximately 0.2 to 1.0 μg/M³. This may be compared with beryllium, which has a maximum allowable concentration of 2.0 μg/M³.

If we assume the average size of dust in the workroom to be one micron in diameter, we can compare the two uraniums easily. For a daily maximum permissible dose, it takes 94 million normal uranium oxide dust particles, one micron in diameter, but only 0.6 million particles of enriched uranium dust of the same diameter. For comparison purposes, the average dust concentration of metropolitan districts is 2 to 10 million particles per cubic foot of air if the median diameter is one micron. The maximum allowable concentration for enriched uranium in these terms is 1700 particles per cubic foot of air if all particles are one micron in diameter.

EXTERNAL RADIATION HAZARDS

The external radiation hazards from uranium are for all practical purposes due entirely to beta particles. The amount of gamma radiation from uranium is negligible, and alpha particles, because of their extremely short range in air and in the skin, make no significant contribution to the external exposure of the body to ionizing radiation.

Since the surface dosage of beta particles from large pieces of normal uranium is 250 mrep per hour, the material may be held in the bare hand for six hours per week without exceeding the 1.5 rep per week hand tolerance accepted by the AEC.[3] The handling time may be increased to 12 hours per week if leather gloves (1 mm thick) are worn.

The external radiation exposure from enriched uranium (oralloy) is negligible because of the small mass handled and the weak beta rays emitted.

Methods of Investigation

Air samples for uranium oxide dust were collected with five different types of samplers: (1) The Filter Queen air sampler, which has been used throughout the rolling experiments at Los Alamos for general air sampling. The dust is collected on a 4 x 9-inch HV #70 filter paper at a rate of 4 cfm. (2) A 1⅛-inch sampling head with either a Whatman #41 or a glass filter paper which collected breathing zone samples at a rate of 20 liters per minute. A portable Gast pump with rotameter attached was used as the source of suction. (3) A hi-volume sampler employing 4-inch diameter glass filter paper was used on rolling operations away from Los Alamos. This sampler collected at a rate of 20 cfm. (4) A portable Gast pump with a 2⅛-inch sampling

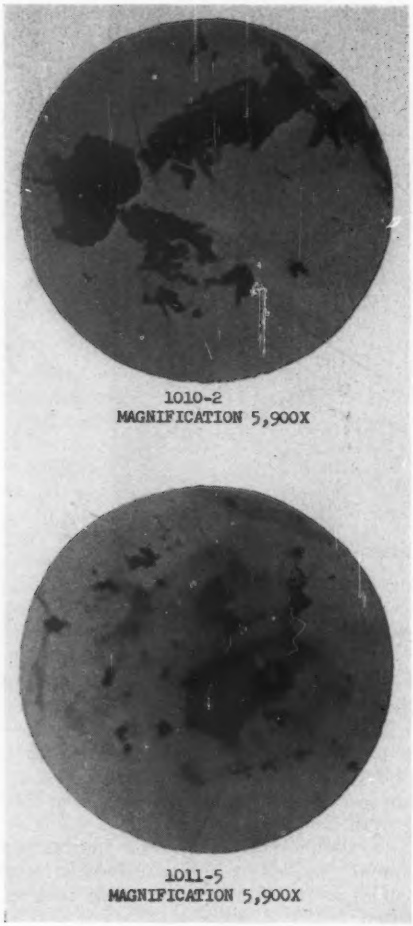

FIGURE 2. Electron micrograph of dust sample collected on Millipore filter directly above rolls during hot (salt bath) rolling. The black U_3O_8 particles are shown as agglomerates in 1010-2 and intimately mixed with salt in 1011-5.

head which drew air through HV #70 filter paper. (5) A continuous sampler, which was operated with a strip of Whatman #4 filter paper. The sampler was regulated to collect samples continuously at hourly intervals.

All filter papers used at Los Alamos during experimental rolling were counted on a methane flow proportional alpha counter with a 2 π geometry. All filter papers used during rolling operations away from Los Alamos were either counted with a portable scintillation alpha counter used in the plant to evaluate the exposures as they progressed or returned to Los Alamos for counting.

Dust Hazards from Rolling Normal Uranium

HOT ROLLING (600–625°C)

The hot rolling caused by far the heaviest air-borne dust concentrations of all the rolling methods studied. For hot rolling, the plates are heated in a carbonate salt bath, which leaves a heavy coating of molten salt on the plate when it is withdrawn for rolling. Since the salt solidifies at approximately 500°C, there is a dust generation problem during the first pass through the roll. It is necessary to make several passes, during which practically all salt originally adhering to the plate is shaken loose and dispersed into the air as dust or else thoroughly covers the mill and the adjacent area.

A thorough study was made of the air-borne dust resulting from the carbonate salt on the plate. The air samples were collected directly above the rolls with a Millipore filter during a typical hot rolling and it was shown that the carbonate dust carries a considerable quantity of uranium oxide aerosols. Representative electron micrographs are shown in Figures 2 and 3. These were prepared and taken by E. H. Kalmus[4] at high magnification, using the electron microscope at LASL.

LASL Experimental Hot Rolling: Hot rolling on uranium (normal and depleted) has been studied at Los Alamos since 1951. Since rigid control measures are enforced, the uranium dust concentration in the workroom atmosphere has never been more than 10% of the tolerance level and no one has ever suffered any ill effects.

The potential hazards from hot rolling normal uranium have been evaluated by air sampling and urinalysis.[5] Both breathing zone and general air samples have been collected since 1951. Since measurements have been low, with the average approximately 10% of tolerance, the results on hundreds of samples collected will not be given here. The effectiveness of the control measures are further emphasized by the fact that the monthly urine analyses have always run between 0 and 10% of LASL's normal uranium urine tolerance of 100 μg per liter.

Hot Rolling at Haynes-Stellite Company: Prior to the rolling operations at the Haynes-Stellite plant, a survey of the plant was made by a representative of the LASL Industrial Hygiene Group. Based on our experience with hot rolling at Los Alamos, it was predicted that over-tolerance air counts would be found and surface contamination would be a major problem. The shearing operation was predicted to be the most

contaminating of the whole operation. Because of this, a portable blower equipped with a CWS-6 type filter was carried to the plant to provide local exhaust ventilation during shearing. The blower exhausted approximately 1200 cfm from the front working area of the shear. In addition to this control measure, the shear crew was required to wear dust respirators at all times.

Measurements on air samples collected during the hot rolling operation indicated that personnel were exposed for short periods of time to airborne contamination above daily tolerance levels (see Table I).

FIGURE 3. Electron micrograph of dust collected on Millipore filter near rolls during hot rolling. In 1009-1 the U_3O_8 (black) is shown as agglomerates and in various sizes as discrete dust particles. The largest agglomerate is approximately 3.5 microns in diameter. In 1008-2, the U_3O_8 crystal structure is clearly shown.

TABLE I

Summary of Air Samples Collected at the Haynes-Stellite Company during Normal Uranium Rolling Operations

No. of samples	Locations and conditions	Conc. of uranium, d/m/M³	
		Maximum	Average
	Rolling		
13	Sampled at breathing zone (BZ) of roller.	67.8	32.8
9	Sampled at BZ of feeder's platform at front of rolls.	29.5	9.6
7	General air samples collected 10 ft from rolls in prevailing air current direction.	18.3	6.3
3	General air samples collected 30 ft from rolls in prevailing air current direction.	7.8	4.6
7	General air samples collected 15 ft from rolls adjacent to salt bath.	140.0	10.2
2	Crane cab operator's breathing zone.	12.3	9.4
7	Sampling head suspended approx. 7 ft above rear of rolls. Represents maximum concentration occurring in dust cloud rising from rear of rolls. No workmen exposed to this.	785.0	417.8
6	Sampling head suspended 7 ft above front of rolls. Represents only dust cloud concentration rising from front of rolls.	227.0	60.9
	Shear		
8	Shear crewmen's exposure. Sampled at breathing level and 1 ft in front of blade.	502.0	266.0
8	Sampled at rear of shear at breathing level and 3 ft to rear of blade.	905.0	474.0
4	General air samples collected in work area approx. 30 ft from shear during shearing.	44.4	27.9

From Table I, it is apparent that the highest air concentrations representing workmen's exposures occurred during the shearing operations. It should be noted that the results of air samples collected in the dust cloud above the rolls do not represent the exposure of any member of the rolling crew. These samples were collected to show that heavy concentrations of uranium oxide dust were generated during rolling and dispersed upwards from the rolls by convection currents. The fact that the roof is 44 feet above the floor made it possible for this heavy concentration to be diluted to a level where no over-tolerance air counts were found in adjacent areas. However, if this operation were to be on a continuous basis, local exhaust hoods would be re-

quired to prevent excessive spread of the dust generated.

Spot samples of urine were collected from all personnel involved in the rolling operation at the beginning and again one day after completion. All results were well below permissible tolerance for uranium in urine. The maximum urine concentration was approximately 10% of tolerance.

WARM ROLLING (to 340°C)

At Los Alamos warm rolling from an oil bath has never created a measurable health hazard. This has been demonstrated through measurements on air samples and by the results obtained from urinalyses. Results of these tests indicate personnel were never exposed to even as much as 10% of tolerance level. A discussion of two warm-rolling experiments, one conducted at the Haynes-Stellite Company and the other at the Rodney Metals Company follows.

Inert Atmosphere Furnace (Haynes-Stellite): One phase of the experimental rolling done at Haynes-Stellite required that the metal be heated in an inert atmosphere furnace, since it was impossible to use salt-coated metal on the Two-Hi mill. In spite of the careful plans to provide the inert atmosphere during the heating cycle, it was found that an oxidizing atmosphere existed during the heating. Extremely heavy oxidation occurred in the furnace, resulting in a layer of oxide approximately ⅛ inch deep. When the metal was removed for rolling, it dragged large quantities of oxide onto the floor and the rolling table, causing excessive surface contamination. In anticipation of the difficulty that might be encountered, all rolling crew members were required to wear respirators during the Two-Hi mill rolling. During the rolling, the hot sheet continued to oxidize rapidly, causing widespread contamination when the sheet bounced and throwing the oxide into the air and over the entire mill.

Air Samples were collected during half a day's operation of the Two-Hi mill, and the results indicated that the concentration of uranium oxide in the air ranged from one to five times tolerance. Thus it was concluded that this method of heating was too hazardous and ineffective to be practical.

Rolling with Sendzimer Mill (Rodney Metals Company): The work involved under this heading was the secondary rolling of normal uranium on a Sendzimer mill. The metal was pickled in nitric acid to remove excess oxide and scale before shipping it to the Rodney Metals Plant. The temperature obtained by infrared heating was not high enough to cause surface oxidation, and the actual rolling proved to be nonhazardous.

Sheets of uranium processed in this operation were the product of the primary rolling operations at the Haynes-Stellite Plant. In order to handle sheets of this size for rolling in the Sendzimir mill, it was necessary to attach stainless steel leader strips to the uranium sheets. The blanking or cutting of holes and riveting proved to be the most contaminating step of the entire rolling operation. Measurements of air samples collected during blanking and riveting gave an average concentration of 45.0 d/m/M³ and a maximum of 92.0 d/m/M³. A total of 50 air samples was collected during the various rolling operations and the maximum concentration was 0.3 d/m/M³. Urinalyses completed on samples collected before and after the rolling operation indicated little or no intake of uranium by the workers. It should be noted that this type of rolling, especially when the sheets are very thin, presents a potential fire hazard during rolling. However, Stearns,[6] of LASL, who has studied the fire hazard concludes that it can easily be controlled. Workmen at the Rodney Metals Company who handled uranium sheets in any manner were required to wear protective clothing.

Dust Hazards from Rolling Enriched Uranium

The Health Division at LASL has made industrial health studies to evaluate the air-borne and surface contamination problems resulting from hot and warm rolling of enriched uranium during experiments at LASL. During the rolling of enriched uranium, all personnel involved have always worn respirators. It was known in advance that this precaution was necessary because the shop used had local exhaust equipment designed to control only normal uranium dust. The only exception made was during the rolling of canned or clad oralloy because, barring an accidental breakage, the can will completely control the spread of oralloy dust.

HOT ROLLING

The results of the health study presented here represent exposures from hot rolling bare enriched uranium metal. The results of measurements of air samples collected during Run #1 are shown in Table II. Three samples collected in the breathing zone of the roller showed an average concentration of 270 d/m/M³. This may be compared with the 14 general room air samples collected during hot rolling that had an average concentration of 35 d/m/M³.

From Table II, it is apparent that the highest air concentrations occurred during the washing of salt from oralloy sheets. The wash tanks were not ventilated. These results, which are more than ten times the concentrations found during rolling, are indicative of air concentrations pres-

TABLE II

Results of Air Samples Collected at LASL during Enriched Uranium Rolling Operations

No. of samples	Operation	Air Conc., d/m/M³*	
		Maximum	Average
	Run #1		
3	Rolling from salt bath. Sampled in breathing zone (BZ) area (hot rolling).	426	270
14	Rolling from salt bath. General room air. Sampled during rolling.	263	35
3	Rolling from oil bath, BZ area; some sparking while rolling (warm rolling).	210	102
4	Washing salt from sheet in water bath; BZ	5360	3580
2	Washing oil from sheet in kerosene bath; BZ	1440	900
4	Shearing washed sheet and cutting; BZ	600	360
2	Inspection room; BZ	177	103
	Run #2		
36	Rolling from salt bath. Sampled between bath and roll (hot rolling).	202	27.0†
95	General work bench beside annealing furnace; center work area. Men are in this area during the majority of time between rollings.	2818	114.0†
42	Rolling from oil bath. Sampler on receiving side of roll(warm rolling).	145	17.0†

* Each sample represents concentration during hour sampled. The air samplers were changed hourly and run during working hours. The 95 samples collected at general work bench represent 95 hours' time at bench.

† These values are weighted average exposure concentrations.

NOTE: Both rolls were equipped with local exhaust hoods.

ent when no local exhaust ventilation is used. It must be remembered that this room has good general ventilation, with an average of twelve air changes per hour.

The results of measurements on air samples collected during Run #2 are also shown in Table II. All air samples summarized in Run #2 must be considered general room air samples. The possible exception to this would be the 95 hourly samples taken at the general work bench. A large variety of operations with oralloy were performed at this bench. When working there, a workman's head was within two feet of the automatic sampler. The average concentration of 114 d/m/M³ at the work bench indicates the necessity of exhaust hoods during preparation, inspection and miscellaneous work with the oralloy. The average concentration of the 36 general room air samples collected during Run #1 compare favorably with those collected during Run #2.

TABLE III

Results of Air Samples Collected at LASL during Special Enriched Uranium Rolling Operations

No. of samples	Operation	Air Conc., d/m/M³	
		Maximum	Average
4	Rolling from salt bath. Sampled at breathing zone (BZ) of feeder (hot rolling).	916	430
2	Heating in salt bath; BZ of heater.	58	45
2	Rolling from oil bath; BZ of receiver (warm rolling).	163	118
4	Washing sheet in water; BZ of washer. Local exhaust duct at wash tank.	184	94
4	Drying after washing; BZ of man drying with rags. No exhaust.	45600	25200
1	Cleaning after oil heat; BZ of man wiping oil off sheet with kerosene-soaked rags.	—	580
1	Shearing; BZ of operator wiping with dry rags, shearing, and wiping again.	—	1980
2	Cutting; BZ of operator while cutting sheet on roll cutter. No exhaust.	3750	2580

NOTE: Local exhaust hoods on both rolling mills.

The results of air samples collected during the rolling of a special enriched uranium are shown in Table III. This metal had a greater specific activity than the regular enriched uranium previously described. It is obvious that both the breathing zone and the general room air samples were higher for this work. The results of measurements on air samples collected during washing operations are lower than those previously shown because the wash tank was equipped with a local exhaust duct. The four samples collected at the breathing zone of a man drying sheets with rags after washing represent the only completely uncontrolled phase of the rolling experiment with this metal. The average concentration of 25,200 d/m/M³ for this drying operation represents the highest air concentration measured during any rolling experiment. It should be noted that each of these four samples was collected over a period of only five to ten minutes.

WARM ROLLING

The air samples collected during warm rolling represent air-borne contamination from rolling bare oralloy metal heated in an oil bath. The oil coating obviously prevents the widespread alpha contamination present during the hot rolling. The results of air samples collected at the breathing zone of the roller and receiver during warm rolling are summarized in Tables II and III. The average concentrations were found to be from 25 to 50% lower than similar work with

hot rolls. We believe that the actual air concentrations were lower than those found because the contamination spread from the hot rolling operations probably contaminates the workroom air during warm rolling. The warm roll and the hot roll mills are approximately 30 feet apart with a common work table between them.

OTHER OPERATIONS

The results of air samples collected during shearing operations indicate concentrations several times tolerance. During these experiments, the shears were not equipped with local exhaust ventilation.

From Table II, the average concentration of two samples collected during inspection of a rolled sheet in another room was 103 d/m/M³. These results are emphasized to point out the need for a local exhaust hood during inspection of the metal. One air sample collected in the breathing zone of the man picking up wrapping paper after completion of the operation was found to be 160 d/m/M³.

External Radiation Hazards from Uranium Rolling

The external radiation hazards from uranium are for all practical purposes due entirely to beta particles. Obviously, the total body radiation is directly related to the size of the uranium pieces handled and the length of time that the workmen are required to work in close proximity to the metal. During LASL's experiments and off-site rolling, personnel wore regulation film badges during the entire operation. These film badges were developed and read at Los Alamos. During the experimental rolling at Los Alamos by both hot and warm rolling methods, workmen have seldom exceeded their weekly beta tolerance level. Workmen involved in off-site rolling experiments have never exceeded their weekly total body beta tolerance. The maximum exposure found in the last five years during normal uranium rolling occurred at the Haynes-Stellite Plant when the shear crew received 80% of their weekly tolerance during a five day period. This is to be expected, since the shearing requires the workmen to be in close proximity to the metal. Part of their exposure, however, resulted from the storage of large piles of sheared sheets. Such exposures could be minimized by installing ¼-inch steel shields between the stored metal and the workmen.

Hazard Control Measures

GENERAL DISCUSSION

The control of uranium radiological hazards is accomplished by a combination of methods.[6, 7, 8, 9] During uranium rolling operations, the only significant hazard is the uranium oxide dust. This dust must, therefore, be kept under control to prevent excessive exposures to personnel in the plant and outside the plant. It is obvious that the process must be engineered to prevent the formation and dispersion of dust. When it is formed and generated, as during hot rolling and shearing, it must be captured at the point of generation by enclosure or local exhaust hoods and exhausted from the building. However, the days are gone when it was thought that poisonous dust could be blown out the window or over the roof and forgotten, or when it could be taken for granted that what goes down the sewer is gone for good. Adequate air cleaning and waste disposal facilities are required.

We must recognize that an external radiation hazard will exist when large masses of normal uranium are handled. We can control the total body beta radiation by shielding, distance and limitation of the exposure.

The control measures required for enriched uranium rolling are much more elaborate and costly. Such areas require cleanliness comparable to that of a modern kitchen. This requirement means that surfaces must be of materials that can be readily cleaned, and, in order to be certain of adequate control, the workroom atmosphere and surfaces must be routinely monitored for alpha contamination. Experience has shown that the cleanest shop floor and equipment are contaminated with uranium dust to some degree. It follows, therefore, that workmen must wear adequate protective clothing and movements of outside visitors must be controlled.

As to the worker himself, he must be educated to be fully aware of the nature and control of potential hazards. He is the key to adequate protection. Generally speaking, he must remember that he is dealing with a hazard which he cannot detect with any of his natural senses. A radiation monitor must be used as a member of the team. The personnel should always be under well-qualified medical supervision.

NUCLEAR SAFETY

One very important problem not evaluated in our study is nuclear safety for processing enriched uranium. Hanks[2] has discussed critical mass limitations of enriched uranium sheet fabrication. Certain operational requirements have been placed on some phases of sheet production to prevent the assembly of a mass that would be critical. These requirements are ascertained using certain safety factors that vary from operation to operation and are valued according to the ease

by which a mistake can be made either accidentally or foolishly.

The following example of critical mass limits is discussed by Hanks. These limits include a maximum of 1 kg of enriched uranium oxide flakes in the K_2CO_3-Li_2CO_3 salt bath used in hot rolling. Since oxide is formed in the salt bath on each billet heated, the build-up of enriched uranium oxide flakes in the salt bath must be carefully controlled. This amount pertains only to the size of the salt pot now in use at Los Alamos and assumes that the flakes are uniformly suspended in the bath. Detailed information on criticality and its determination have been published by Paxton[10] and Graves.[11]

STORAGE OF URANIUM BILLETS

The storage of normal uranium presents no dust problems. Enriched uranium billets should be stored in covered cans in a well-ventilated vault. Adequate nuclear safety precautions for storage of enriched uranium billets must be calculated.

BILLET OR SHEET HEATING

A local exhaust hood is necessary when bare enriched uranium is prepared for rolling or when welding is used to can and seal the metal. A canopy hood should be installed over the salt bath. The hot oil bath gives off noxious fumes and should be equipped with a slot exhaust hood, similar to plating tanks.

HOT BREAKDOWN ROLLING

It is necessary to install local exhaust ventilation on the hot rolling mill when normal uranium is worked. An example of a slot-type exhaust hood installed on the Two-Hi Bliss mill at LASL is shown in Figure 1. The slots are 21 x 4 inches and are connected to an 8-inch exhaust duct that draws 1500 cfm through the two slots. If bare enriched uranium metal is hot rolled for production, it would be necessary to completely enclose the mill with minimum openings to work the metal. When larger mills are used, such as the Three-Hi mill at the Haynes-Stellite plant, slot exhaust hoods should be installed on both sides of the rolling table for normal and enriched uranium rolling.

WARM SECONDARY ROLLING

When warm rolling from an oil bath, the oil coating prevents extensive dispersion of U_3O_8 dust. The rolls should be equipped with local exhaust hoods. If the Sendzimer mill is used for rolling normal uranium, no local exhaust is required. If enriched uranium is rolled, the Sendzimer mill should be equipped with local exhaust enclosures.

WASHING SHEET

For enriched uranium only, the wash tanks of water, kerosene, etc., should be equipped with slot-type local exhaust hoods similar to plating tanks. In addition, the drying table should be equipped with a slot-type local exhaust hood on the back of the bench.

SHEARING

The shears are the most contaminating operation and must be equipped with local exhaust ventilation. An example of slot-type local exhaust hoods at the front and rear of the shear blade is shown in Figure 4. The exhaust slot at the rear of the blade is 72 x 4 inches and exhausts 1500 cfm. The sloping surface on the rear exhaust plenum allows the sheared metal to slide to the floor. The front slot (80 x 3 inches) exhausts 750 cfm. If the sheet is not washed before shearing, slot-type exhaust hoods should be installed on approach and receiving tables.

WASTE DISPOSAL

Facilities must be provided for adequate waste disposal. This includes solid, liquid and air-borne wastes. Normal uranium wastes present problems of disposal. All enriched uranium wastes, because of their intrinsic value, must be saved for recovery.

The disposal of solid wastes is usually done according to facilities available at the plant. Isolated plants may bury solid wastes. Plants located in metropolitan areas must work out a suitable and safe disposal method with local health department officials.

Liquid wastes must be filtered or run into settling basins before disposal. The safe concentration of uranium in liquids for disposal into streams has been established by the AEC.[12]

All contaminated air exhausted from uranium rolling operations must be cleaned. The degree of air cleaning will depend upon the congestion near the plant. Air-borne enriched uranium dust should be filtered with an AEC CWS-6 filter or equivalent, preceded by a roughing filter.

Summary

Industrial health surveys have been made over a period of 5 years during rolling operations with normal uranium at LASL and at two off-site plants. The results indicated that personnel participating in this work were not exposed to above-tolerance levels of external or internal radiation hazards. The external radiation hazards were evaluated by means of personnel film badges. The

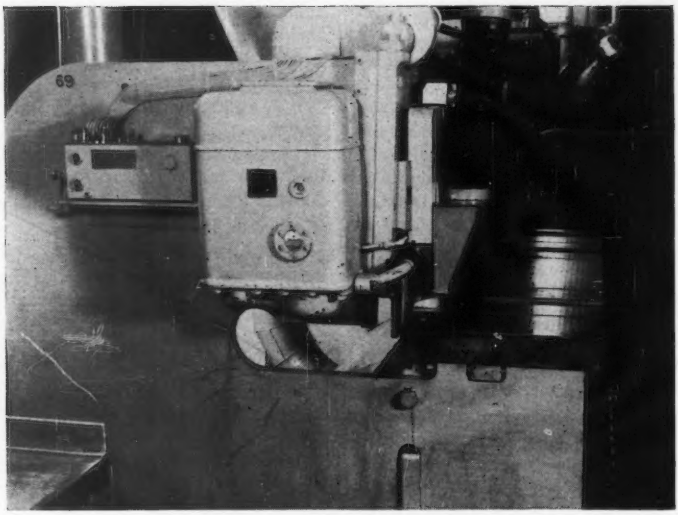

FIGURE 4. A view of the LASL shear showing the slot-type exhaust hood in front of the shear blade and a portion of the exhaust slot which is located to the rear and below the blade. The sloping surface of the exhaust plenum allows the sheared metal to slide to the floor. The front slot (80 by 3 inches) exhausts 750 cfm and the rear slot (72 by 4 inches) exhausts 1500 cfm.

internal hazards from alpha active particles were measured by means of air and urine samples.

The exposure at LASL during normal uranium rolling (with adequate ventilation) never exceeded 10% of tolerance. During hot rolling (primary) operations at an off-site plant, with inadequate or no ventilation, personnel were exposed to levels of air-borne contamination above daily tolerance levels for short periods of time. During warm rolling (secondary) operations with normal uranium at a second off-site plant, exposures were less than 10% of daily tolerance levels.

Industrial health surveys have been made during enriched uranium rolling operations at LASL. These rolling operations were performed in a workroom with ventilation designed for normal uranium operations. Results of air sampling indicate personnel were exposed to air concentrations above tolerance for short periods of time. Results of urine analysis showed the average exposures never exceeded 20% of tolerance.

Hot rolling from salt baths presents the greatest hazards. Hazards during warm rolling from oil baths are minimal. Recommendations are given for the control of health hazards.

Acknowledgments

The author wishes to acknowledge the cooperative effort of the Radiation Monitoring Group (H-1) and the Industrial Hygiene Group (H-5), of LASL's Health Division, in the studies made of the rolling experiments at LASL and off-site. The Radiation Monitoring personnel assisted in the collection of air samples as well as assuming the responsibility of surface monitoring, evaluation and control.

The co-operation and assistance of personnel from the Fabrication Section of Group CMB-6, of LASL, are gratefully acknowledged. The Section Leader, G. S. Hanks, and Group Leader, J. M. Taub, considered the industrial health personnel as part of the rolling crew on every job undertaken.

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Diamond Jubilee

THE NATIONAL SOCIETY FOR CLEAN AIR (England) will sponsor a Diamond Jubilee International Clean Air Conference and Exhibition in London on October 20 through 23, 1959. This Conference will also celebrate the sixtieth anniversary of the founding of the Society which as the Coal Smoke Abatement Society was established in London in 1899. The practical action required for the progressive reduction or abolition of air pollution will be the prime concern of the Conference.

Six main conference sessions will be held during the first three days and the final day will be devoted to visits and excursions of air pollution interest. Conference sessions will be devoted to the following themes: (1) legislation; (2) public opinion and education; (3) technical papers; (4) international co-operation, studies and information exchange; and (5) research and investigations.

Interested persons, groups, or agencies are invited to contribute written communications for any of these sessions. Contributions should be limited to subject matter of the session and preferably should not exceed 1,000 words. Photographs and other illustrations may be included. The Conference sessions will be in the form of discussions on the written papers which will be printed and distributed to registrants in advance of the Conference. Proceedings of the Conference will be published subsequently. Written contributions must be received by July 1, 1959.

Contributions, registrations, and inquiries should be addressed to Arnold Marsh, Director and Secretary, National Society for Clean Air, Palace Chambers, Bridge Street, London, S.W.1, England.

Surface Contamination Control with Uranium Rolling Operations*

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Introduction

SINCE the advent of the "Atomic Age," a transfer of certain operations from the laboratory to private industry has been effected. With this progression, industry has been confronted with new materials foreign to their standard operating procedures. The purpose of this report is to present the monitoring and decontamination results of the Los Alamos Scientific Laboratory (LASL), Haynes-Stellite Wrought Alloy Plant, and Rodney Metals, Inc., for work similar to the operations currently confronting industry in the rolling of U-238 and U-235. This report will be confined to the levels of contamination found on equipment, both as to direct count and to the material that readily rubs off, and of their control and consequence during the rolling of uranium billets into sheets.

The machinery and immediate work area will become contaminated and will require constant monitoring and decontamination surveillance in order to keep personnel exposure levels below accepted limits. The desirable surface count for personnel and equipment at LASL for U-235 and U-238 has been established as 2000 disintegrations per minute per 50 square centimeter (d/m/50 cm^2) alpha as measured with a probe having 50 cm^2 area. Actually, the figure of 2000 d/m should be considered as a base line for operations, whereas a higher count may still be allowable for routine work, providing the contamination is embedded and will not swipe from the surface. Swipes can be obtained by rubbing the area with porous cloth or paper and can be counted on a portable alpha instrument. Swipes showing any detectable activity are indicative of loose contamination and suggest a need for cleanup. Although beta-gamma contamination is not much of a problem, it provides another method of measurement in cases where surfaces are covered with oil and alpha monitoring is difficult.

* This study was performed under the auspices of the Atomic Energy Commission.

Instrumentation and Methods of Measurement

INSTRUMENTS

Four types of detection instruments were used in the radiation surveys at LASL, Haynes-Stellite Wrought Alloy Plant, and Rodney Metals, Inc. Surveys for beta contamination were made using a beta-gamma Geiger-Müeller type instrument. Alpha surveys were made using a proportional alpha counter. Any alpha instrument may be used providing it will not pick up beta-gamma radiation also. For floor surfaces, a special alpha floor monitoring instrument[1] was used. This instrument was built at LASL, using a standard proportional alpha-counter circuit mounted on a carriage and equipped with a probe covering 340 cm^2 which was located one cm from the floor.

The beta-gamma detection instruments were calibrated using radium standards, with frequent operational checks being made from a normal uranium standard during the surveys. The alpha detection instruments were calibrated with a normal uranium standard each time before using, and frequent checks were made with the same standards during surveys. The values of millirads per hour (mrad/hr) with the shield open are merely orders of magnitude and not actual beta dose rates. No standard ratio of beta to alpha reading can be given as the variation is so great. The ratio will depend largely upon the type of equipment and depth of embedded material. For comparison readings, see Table I.

SPECIAL PROBLEMS

Oil and Salt-coated Surfaces. The machinery and machine areas were surveyed for alpha or beta radiation, depending upon the type of surface to be monitored. During rolling operations where an oil bath was used, alpha monitoring with any degree of accuracy was impossible due to the oil-coated surfaces. These surfaces were surveyed for beta-gamma with the probe shield open and in direct contact with the surface being checked. Where the type of operation made it feasible, the alpha detection instrument was most

TABLE I

Comparison of Alpha and Beta Counts from Cleaned Surfaces

Results of alpha and beta counts taken from surfaces which had been cleaned to the level at which no positive swipe reading could be obtained. The readings were taken in areas where both U-235 and U-238 had been processed.

Location	Alpha d/m/50 cm²	Beta mrad/hr
Floor	600	0.70
Floor	700	0.15
Floor	900	0.25
Floor	600	0.25
Floor	200	0.10
Floor	300	0.25
Floor	500	0.10
Floor	450	0.00
Floor	100	0.00
Roller	7000	0.30
Shears	2000	0.80
Shears	3000	0.50
Saw	5000	3.00
Roller	40000	0.20
Washing table	5000	0.80

frequently used owing to its sensitivity in reading extremely low level uranium contamination.

Rough and Uneven Surfaces. Contamination measurements on rough and uneven surfaces presented the greatest problems. At LASL, the floor surfaces were smooth enough to permit scanning the areas with an alpha floor monitor. At both off-site plants, the floor surfaces were rough and uneven in some areas, making the use of the floor monitor impractical. In cases not suited to the use of the floor monitor, the portable proportional alpha counter had to be utilized. Deep cracks in the floor and small openings in the machinery were surveyed with a beta-gamma instrument because of the limited range of alpha particles.

NORMAL URANIUM PROCESSING

Salt Bath Operation and Hot Rolling at LASL. Billets that were hot rolled in the two-high Bliss Mill and that were heated in a 625°C salt bath (see Figure 1) resulted in alpha contamination to adjacent areas ranging from 2,000 to 40,000 d/m/50 cm².

Personnel working in the area were supplied with disposable clothing including caps, coveralls, safety shoes, booties, cotton gloves, safety glasses, and ultrafilter respirators. During rolling operations, the immediate area was roped off to prevent other personnel from entering and tracking loose material to other sections of the room.

Vacuum cleaners equipped with CWS-6 filters were used to pick up loose oxide and salt flakes during the operation. This prevented contamination from becoming airborne and equipment from becoming impregnated.

Before personnel left the immediate area, they were monitored and contaminated clothing or equipment was removed. A wash room was provided for use by personnel who may have received contamination to the skin. A washing with soap or detergent usually removed any contamination from the skin. When the personnel returned to the area, they were supplied with clean work clothing.

At the end of each operational phase, or when the contamination reached a level at which adjacent areas were likely to become contaminated, a thorough cleaning was accomplished on equipment and the area. Floor contamination has ranged from 2,000 to 40,000 d/m/50 cm² and contamination on the rolls up to 50,000 d/m/50 cm² before decontamination. The floors were vacuumed before scrubbing took place. Scrubbing was accomplished by using an electric floor scrubber equipped with stiff bristled brushes. The reservoir tank of the scrubber contained liquid soap solution which was metered out to the area being scrubbed. Following each scrubbing, a squeegee connected to a wet vacuum pick-up cleaner was used to remove excess water and the floor was then dry mopped. In most instances this reduced contamination in the area to a negligible count. In areas where material had become embedded in the concrete floor, several scrubbings were necessary to reduce the count to an acceptable level. The rollers were more difficult to clean. Rags dampened with trichlorethylene were the most effective. When this solvent is used, care should be taken to assure that the area is well ventilated. The rolls were scrubbed until no radioactive contamination would swipe off. Since the mill was to be used for future rolling of the same material, further decontamination was impractical as the contact count was down to approximately 10,000 d/m/50 cm² maximum.

Oil Bath Operation or Warm Rolling at LASL. The problems encountered during rolling operations, in which an oil bath of approximately 325°C was used in conjunction with a four-high Loewry rolling mill (see Figure 2), are somewhat different. The airborne activity was usually low; however, fires, on occasion, greatly increased the concentration. The same protection as listed under the salt bath operations sufficed.

In this type of operation, the floor was covered with Kraft paper to reduce contamination from dripping oil. When the floor area was cleaned,

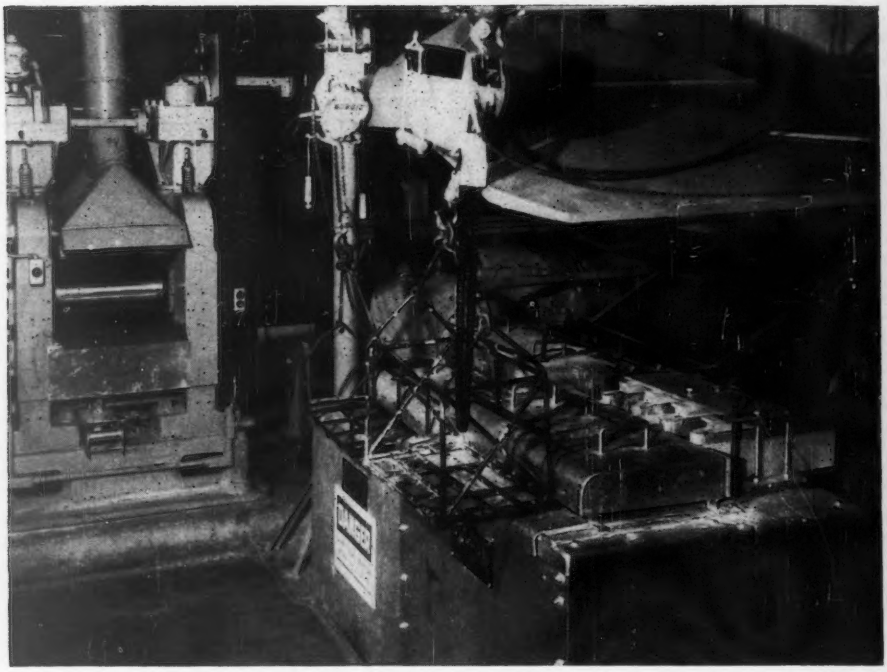

FIGURE 1. Two-high Bliss Rolling Mill with the salt bath in the foreground at right. This also gives an excellent view of the cradles used to hold the uranium billets for heating.

the paper was carefully folded by starting at the outer edge and folding toward the center. The paper was boxed for disposal. (Use of paper on the floor during the salt bath operation was impractical due to the fire hazard from flakes of molten salt falling from the billets.)

Decontamination for this operation was somewhat different than for rolling from a salt bath. The loose scale was absent from the floor and mill so that a vacuum cleaner was not used. After the paper was removed from the floor, oil traces were cleaned with kerosene. Before decontamination, alpha contamination ranged up to 50,000 d/m/50 cm^2 with an average of 10,000 d/m/50 cm^2. After the oil was removed from the surface, the cleaning procedure as listed for the salt bath operations was followed. The rolls, after decontamination, remained contaminated to the extent of 5,000 d/m/50 cm^2.

Hot Rolling—Haynes-Stellite Wrought Alloy Plant. Rolling operations consisted of rolling U-238 billets in a three-high mill (see Figure 3) after they had been heated in a 625°C salt bath. Scale formed on the surface of the sheet with exudation taking place; therefore, a protective coat of asbestos-mat floorcovering was laid around the salt bath and the area between the salt bath and roller table. The pit under the mill was not cleaned before the operation began as it was felt that this accumulation of grease would act as a collector for falling oxide and scale.

During rolling operations, sheets were accumulated on the skid table at one end of the roller table. When cool, several sheets at a time were taken to the shears for trimming. Two vacuum cleaners were in constant use around the roller tables, skid tables, and shears to remove loose material before it could spread to other parts of the plant. The sheets were cleaned with vacuum cleaners before the shearing operation, and a janitor was stationed both in front and back of the shears to remove with a vacuum cleaner loose scale from the sheets, floor, and shears.

One sheet was taken immediately from the shears to a two-high rolling mill. There was a very loud crunching sound on the sixth pass through the mill with a considerable amount of flame developing for a period of one second. The bottom roll had broken and a spot approximately 5 x 1 inches was burned on the broken roll. This spot was contaminated to the extent of 10 mrad/hr beta and 30,000 d/m/50 cm^2 alpha.

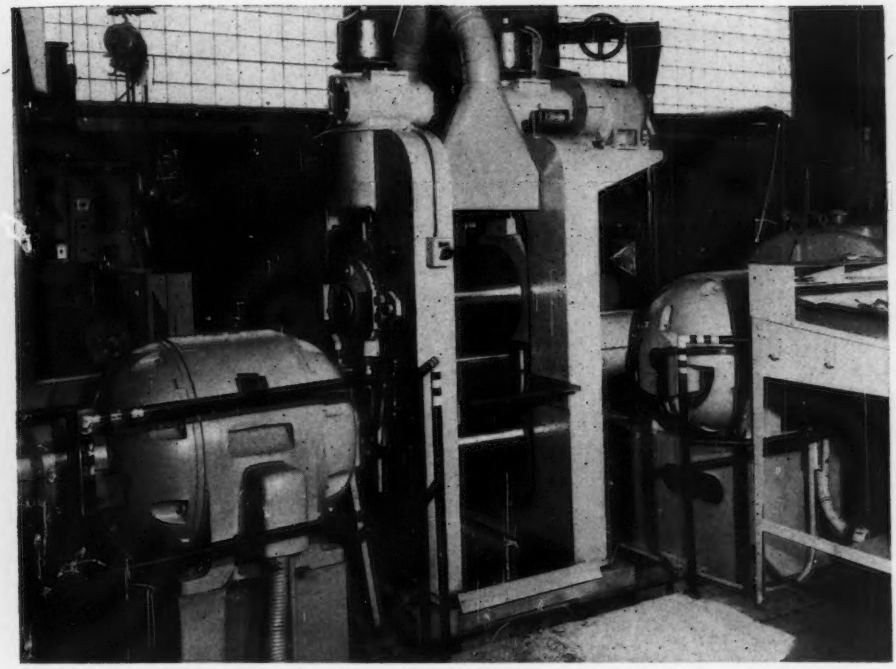

FIGURE 2. Four-high Loewry Rolling Mill used in rolling uranium that has been heated in an oil bath such as the one in the background at left directly beneath the hoist.

The entire area was vacuum cleaned and the broken roll removed and replaced. Very little success was achieved in cleaning the burned spot of the broken roll. The second sheet to be rolled in the two-high mill was first placed in an electric furnace in an argon atmosphere and heated to approximately 350°C in preparation for rolling. After passing through the mill several times, the sheet was coated with oxide scale that caused considerable contamination to the two-high mill but was readily cleaned with a vacuum cleaner. The inside of the electric furnace had a coating of oxide ⅛ inch deep that had to be removed with a vacuum cleaner.

At the end of a working day, a thorough cleaning was done to prevent personnel on later shifts from tracking the material. Large metal pans, which had been placed under the roller tables to catch falling scale, were removed and cleaned. The roller tables and platforms were vacuum cleaned, brushed with stiff brushes, and re-vacuum cleaned. The entire area was washed down with water at the end of each shift. The run-off drained into a stream running under the mill which ran to a settling pond. It was held in the pond for a considerable length of time to permit the particles to settle before being dumped.

Personnel wore the same type of work clothing as described under LASL operations and frequent contamination surveys were made of the personnel during the day and also before they left the immediate work area. Gloves became contaminated to the extent of 3,000 d/m/50 cm^2 and were placed in containers for removal from the area. Shoes, in several cases, picked up as much as 1,000 d/m/50 cm^2 but were easily cleaned with a damp cloth. At the end of the operation, all shoes were washed with soap and water which resulted in a zero count remaining.

Oil and Strip Heater Operations at Rodney Metals, Inc. The rolling of uranium sheets at Rodney Metals, Inc., was a moderately clean operation. The material to be rolled was thinner than material processed at the two previous installations. Stainless steel leaders were attached to the ends of each sheet by rivets. The material was heated by strip heaters located at each end of the mill. The sheet being rolled had to be closely watched to prevent overheating and possible fires. Oil was continually sprayed on the sheets while they were being drawn through the

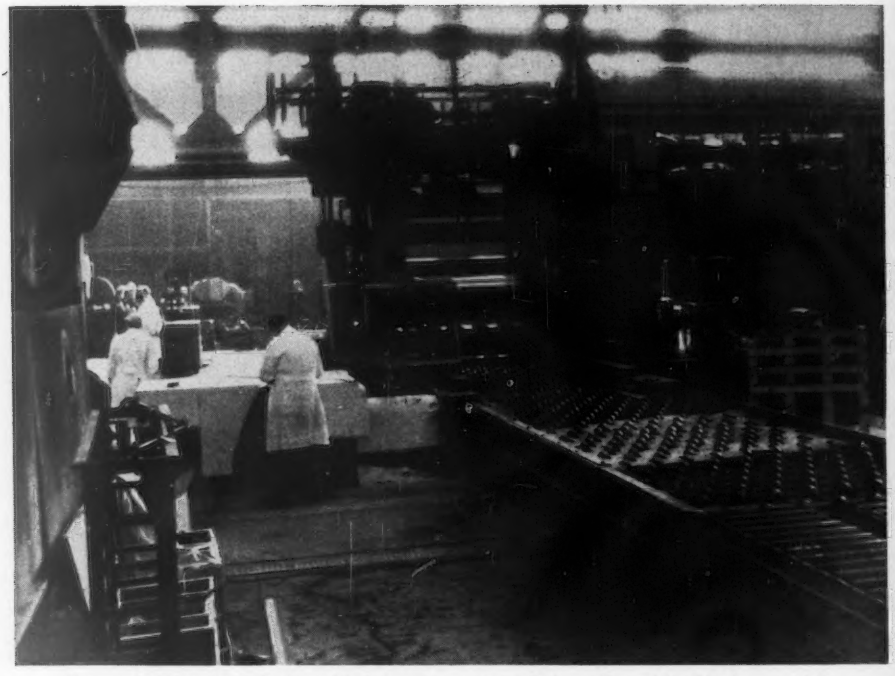

FIGURE 3. Three-high Rolling Mill showing a view of the roller table. Platform at left is covered with sheet asbestos to protect it from molten salt as the billets are carried from the salt bath at extreme left (out of picture) to the roller table in preparation for rolling.

cluster mill. Wiper blades were also mounted at each end of the mill to wipe excess oil from the sheets. No fires occurred during the rolling process and the operation was handled with only slight contamination to the mill and area. These areas were cleaned daily; therefore, contamination spread was never a serious problem.

ENRICHED URANIUM PROCESSING

Salt Bath Operation at LASL. The salt bath rolling was similar to the rolling of normal uranium except that some areas received a higher specific count due to U-235. Gloves and tongs used to handle the material were alpha-contaminated to a level of 50,000 d/m/50 cm². The rolls of the two-high mill were contaminated in excess of 100,000 d/m/50 cm². The floor areas were decontaminated quite readily with simple scrubbings, but the rolls remained contaminated to a level of 40,000 d/m/50 cm² with a negligible swipe count. Clothing contamination was kept to a minimum with the exception of gloves which were discarded and replaced several times a day.

Oil Bath Operation at LASL. Rolling operations from the oil bath on the four-high Loewry mill were very similar to those for normal uranium. The immediate floor area became contaminated to a level of approximately 50,000 d/m/50 cm², with rolls measuring in excess of 100,000 d/m/50 cm². The decontamination methods were the same as for normal uranium, but higher levels were found in impregnated spots on the floor that read approximately 40,000 d/m/50 cm² with no swipe count. The rolls were cleaned with trichlorethylene in order to reduce the swipe count to an insignificant level. The contact level remained at approximately 50,000 d/m/50 cm².

Decontamination at Off-site Plants

HAYNES-STELLITE WROUGHT ALLOY PLANT

After operations had been completed, a general cleanup was initiated to remove all loose contamination and reduce the over-all count to the lowest point practical. (See Tables II and III for before and after decontamination monitoring results.) The work area and all machines were vacuum cleaned where it was practical. The pits under the rolling mill were scraped free of grease. The grease scrapings, which contained loose oxide and scale,

were placed in steel drums for disposal. The pits under the mill were washed down with a high pressure stream of water from a fire hose. The floor areas and machines were sprayed with water and then scrubbed with a detergent and water. The rolls were scrubbed to remove as much activity as possible. The shears were washed with soap and water but this method of cleaning failed to reduce the count to the desired level. KW solution (Igepal CA Extra 1 cc; citric acid powder 5.76 grams; Versene, Fe specific, 2 cc; water 1 liter) was used to scrub the shears, guides, blade, and backdrop, thus reducing the alpha contamination to an acceptable level. No spot in the plant had in excess of 200 d/m/50 cm² on a swipe. The highest swipe resulted from the top of the shears.

RODNEY METALS, INC.

The general cleanup was accomplished without the effort put forth at Haynes-Stellite Wrought Alloy Plant. The sheets rolled had a smoother surface and no problems were encountered with loose flakes of oxide. The area was cleaned daily by normal janitorial cleaning methods. The mill was partially disassembled by removing the rolls, bearings, and screens. The pieces of uranium that had broken off during rolling were recovered at this time. Parts of the mill that had come in contact with the uranium were cleaned and dried, then rechecked with an alpha proportional instrument with negative results. All parts were monitored with a beta-gamma detection instrument and no activity could be found. The mill and surrounding work area were thoroughly monitored, in addition to the sludge in the drainage filter system, but no activity could be detected. Wiper blades from the mill showed a slight trace of contamination and were placed in drums for disposal.

Conclusions

The problems encountered were found to be more of a technical nature than one of great health hazard. The considerations for enriched uranium were found to be essentially the same as for normal uranium except for the magnification of specific activity levels. Strip heating of uranium and rollers resulted in the least amount of contamination spread, with the exception of wiper blades. Heating uranium in an oil bath prior to rolling resulted in the second least contamination spread, and salt bath and furnace heat methods resulted in the greatest amount of contamination spread.

Work clothing issue and change room facilities reduce contamination to personnel as well as confining contamination activity within the plant. Personnel must be monitored for contamination as they leave the area both as a health check and

TABLE II

Effectiveness of Decontamination Procedures

Summary of predecontamination and postdecontamination surveys at Haynes-Stellite Wrought Alloy Plant. The results were based on approximately 3000 individual readings taken on the floor area and three-high mill.

Location	Predecontamination alpha d/m/50 cm²		Postdecontamination alpha d/m/50 cm²	
	Average	High	Average	High
Rails on skid	6,000	12,000	3,000	9,000
Rollers on last roller table	1,100	2,400	600	1,600
Rollers with wheels on last roller table	3,000	10,000	700	5,000
Roller guides	8,000	16,000	600	1,400
Large rollers	400	1,000	100	1,000
Northeast platform	50	200	50	200
Southeast platform	50	200	50	200
Platform around tank of salt bath	300	1,600	25	200
Rollers with wheels on west roller table	2,500	8,000	700	6,000
Rollers on west roller table	800	2,000	600	1,400
Northwest platform	50	200	50	200
East floor area	400	1,200	50	200
South floor area	50	600	25	100
West floor area	50	400	25	100
North floor area	100	600	25	100

TABLE III

Effectiveness of Decontamination Procedures

Summary of predecontamination and postdecontamination surveys at Haynes-Stellite Wrought Alloy Plant. The results were based on approximately 2,200 individual readings taken on the floor area and shear equipment.

Location	Predecontamination alpha d/m/50 cm²		Postdecontamination alpha d/m/50 cm²	
	Average	High	Average	High
Platform guides	3,000	10,000	50	800
Cutting table	5,000	24,000	800	7,000
Blade	15,000	28,000	400	4,400
Back drop—curved steel plate	4,000	16,000	1,600	16,000
Portable roller table	1,000	8,000	100	1,600
Steel plate on floor, rear of shears	6,000	22,000	700	4,000
North floor area	2,000	10,000	100	1,860
East floor area	100	800	50	200
West floor area	800	2,000	50	400
South floor area	4,000	12,000	100	600
Storage area of sheared sheets	4,000	10,000	100	800

also to indicate a trend on operating controls. It has been found that waste water from such areas has not exceeded the drinking water tolerance providing it has been properly filtered. Contaminated clothing must be processed by laundry facilities segregated from those handling ordinary clothes.

Shearing operations created more problems than rolling since the material had to be handled longer while it was being sheared. This operation results in the greatest external radiation to the body, in addition to creating high airborne contamination, unless adequate ventilation is provided directly at the shears. Contaminated residue had to be placed in containers and disposed of in accordance with AEC and local requirements. Frequent surface monitoring was the key to contamination control. With the exercise of proper contamination and fire control, the hazard encountered by personnel was nil.

Acknowledgments

The author wishes to thank Carl W. Buckland of this Laboratory for his assistance in the preparation of this report; also Edwin C. Hyatt, Harry S. Jordan, and Alex Gutierrez, all of this Laboratory, for their assistance with the technical work necessary for carrying out this investigation.

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Diatomaceous Earth

A REPORT DESCRIBING the results of an epidemiologic study of diatomaceous earth pneumoconiosis in five diatomite plants in the western states has been released by the U.S. Public Health Service. The findings confirm that cristobalite, which is produced in the calcining of the natural product, increases the hazard of pulmonary injury and that amorphous or natural diatomite is distinctly less hazardous. Threshold limit values for the different forms of diatomite are not given, however, it is indicated that exposures to products containing more than five per cent cristobalite probably should not exceed five million particles per cubic foot of air. Similarly, amorphous diatomite should be kept below 20 million particles per cubic foot until data are available to define its biologic activity, including its effect relative to superimposed infections.

This study has defined the pneumoconiosis problems of the diatomite industry much better than was previously known. Recommendations from the study emphasize engineering controls of exposures, periodic medical examinations of workers, frequent assessment of the pulmonary status of employees, and precautionary labeling of products.

Copies of the report, *Pneumoconiosis in Diatomite Mining and Processing* (Public Health Publication No. 601) are available from the Public Health Service, U.S. Department of Health, Education, and Welfare, Washington 25, D.C.

Particle Size Studies on Uranium Aerosols from Machining and Metallurgy Operations*

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THE PARTICLE size of an air-borne dust is recognized as an important parameter in evaluating its health significance. Permissible concentrations are calculated with certain assumptions regarding the deposition and retention of the dust in the human respiratory tract and particularly in the alveolar section of this tract. These assumptions may be based on animal studies, where a dust of a particular size range is used, or on human studies, in which a wide variety of size ranges has been studied. In either case, a definite assumption is made regarding the size characteristics of the inhaled dust. This aspect of radioactive particulate hazards has been discussed by Burnett and Hatch.[1] Also, in selecting filter papers for air sampling or devices for air cleaning, assumptions regarding particle size must be made in order to predict their efficiencies. In laboratory studies on animals, humans and filters, size information is usually available on the test dust used. Nevertheless, very few field determinations of particle size are reported in the literature, particularly on radioactive dusts. This leaves open to serious question whether the laboratory data can be directly applied to field conditions. A fair amount of data is available on silicosis-producing dusts and this data is well supported by clinical studies on persons who have acquired disabilities as a result of breathing such dusts.

On the other hand, permissible concentrations of radioactive dusts are largely calculated without the benefit of clinical data, since the control measures, so far, have been outstandingly successful in preventing the existance of such clinical material. Size data is needed, but very little has been presented. Adley[2] and his co-workers have reported particle size data on certain normal uranium fabrication operations and Fitzgerald[3] has reported data on stack samples. Considerably more such data is probably resting in the files of various organizations but much more is needed. There is a very real reason why this data is largely unavailable: it is extremely difficult to collect field data on the particle size of radioactive dusts. The basic method of measuring particle size is to collect a sample in an impinger or on a filter paper and then to measure the size under a microscope. It is not difficult to obtain a satisfactory sample of dust for this purpose around hazardous, dusty operations involving nonradioactive dusts. The sample obtained and examined under the microscope consists largely of the dust to be studied. With radioactive dusts, concentrations are usually kept quite low and the sample obtained contains a relatively small percentage of the radioactive dust. There is generally no way to identify the radioactive particles and to distinguish them from the bulk of the nonradioactive dust. Hence, indirect methods have had to be employed for making this measurement.

Method of Investigation

The instrument most frequently employed for this purpose has been the cascade impactor, and our data is based largely on the field use of this instrument. In the impactor, the dust is sorted out into a series of decreasing but overlapping size ranges as illustrated in Figure 1. If the instrument has been properly calibrated by optical sizing of samples of a similar dust collected in a dust chamber, it should be capable of giving at least a fair estimate of the mass geometric median diameter (M'_g) and the geometric standard deviation (sigma or σ_g) of the sizes. If the sizes of the dust follow the logarithmic probability distribution demonstrated on most dusts, these two parameters are all that are necessary to characterize the dust dispersion.

We constructed a cascade impactor at Los Alamos in 1950, based on drawings and dimensions supplied by Sidney Laskin of the University of Rochester[4] (U. of R.) for their impactor. Their impactor had been carefully calibrated in a dust chamber against uranium oxide (UO_2) dust. The Los Alamos impactor (hereafter referred to as the Laskin impactor) was later calibrated against the U. of R. instrument in the same dust chamber and was found to check very closely. There was a

* These studies were performed under the auspices of the U.S. Atomic Energy Commission.

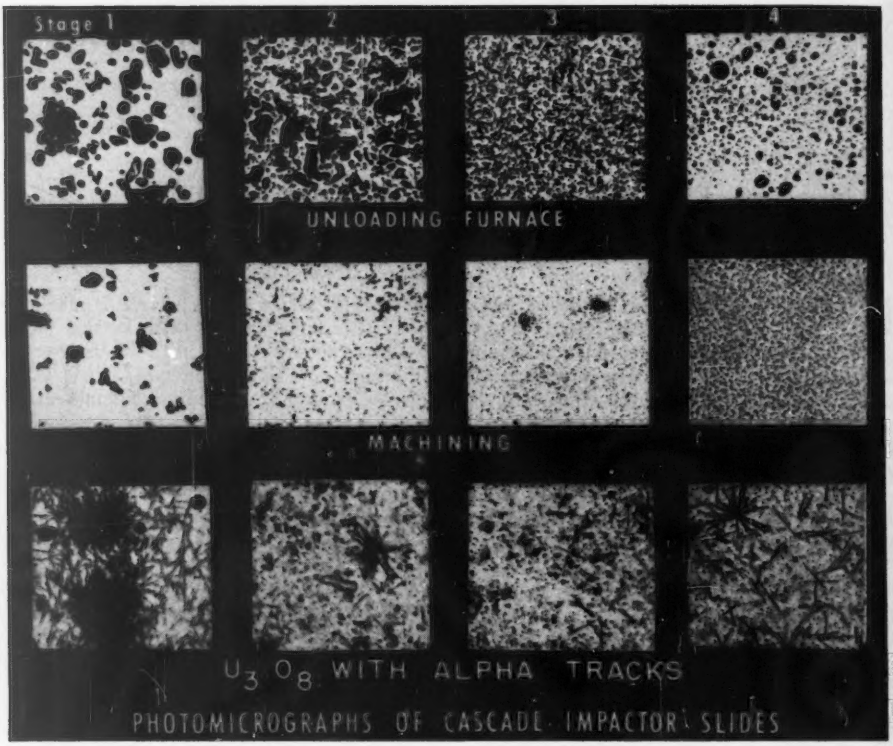

FIGURE 1. Photograph of cascade impactor slides illustrating separation into size fractions with some overlapping. The numerous alpha tracks from two large particles of enriched U_3O_8 machine shop dust on Stage 1 emanate from particles 10 to 20 microns in diameter.

difference of only 3.1% in the mass median diameter as measured by the two impactors and no difference in the geometric standard deviation. All the data we are reporting is on uranium dusts, which were assumed to be U_3O_8 with a density of 7.0 gms/cm^3.

The Casella impactor has also been used in many of the determinations given here. It differs from the Laskin impactor in having higher jet velocities on the last two jet stages. Calibrations on these stages can be calculated from the U. of R. calibrations on the basis of the fundamental impaction equation:

$$\rho V D^2 = \text{constant}$$

where ρ = density of the dust particles
V = jet velocity
D = stage median diameter

The results are shown in Table I.

The Casella impactor has been checked against the Laskin impactor using these calculated medians, both in the chamber at the U. of R. and in the field at Los Alamos. Excellent agreement has been obtained in the dust chamber and good agreement in the field.

Material already deposited on one stage may be subsequently re-entrained and carried to a later stage. This is quite serious if dry collection slides are used but not if a thin film of tacky material is coated on the slides. The material must be thin enough not to interfere with alpha particle emission. We have checked direct counts of uranium activity on slides against chemical analyses of these same slides and found good agreement, indicating that absorption losses are minimal. Shattering of particles is not a problem in the absence of re-entrainment except in the original calibration of the impactor.

First et al.,[5] have named three major mechanical defects of the Casella cascade impactor. They are: (1) air leaks from openings or cracks in soldered joints, (2) air leaks around the rubber end-caps, and (3) dust deposits on the walls of the impactor. We checked the amount of air

TABLE I

Stage Media Calibrations for the Laskin and Casella Impactors

(U_3O_8 Dusts; Density = 7.0 gms/cm³)

Stage	Mass Median Diameter (μ)	
	Laskin	Casella
1	4.94	4.94
2	2.08	2.08
3	1.09	0.89
4	0.72	0.45
5	0.44	0.31

leaking through soldered seams, etc., and found that the leak amounted to 1 to 3% of the 17.5 liters per minute sampling rate. One impactor leaked 10% of the air sampled and had to be soldered.

We believe that the rubber caps, as provided, are a defect. We have modified two Casella impactors by adding threaded metal end-caps containing rubber gaskets, as shown in Figure 2. However, we have found that a strip of Scotch electrical tape placed around the rubber cap and onto the walls of the tube will provide an air-tight seal and prevent the caps from falling off during use. We also use this tape to seal the seams that are exposed when the four stages are assembled. The modification with metal end-caps is preferable, but the rubber caps may be used when taped to the tubes, so that there are only minimal air leaks.

First has found as much as 30% desposited on the walls when sampling copper sulfate spheres from ducts. We have made similar measurements following uranium oxide sampling in free air, but have found much less deposition.

Results

FOUNDRY OPERATIONS

A summary of measurements on cascade impactor samples collected for both normal and enriched uranium during various foundry operations is shown in Table II. It should be emphasized that the specific activity of enriched uranium is from 100 to 200 times greater than that for normal uranium. The unloading and breakout refer to the unloading of the graphite mold from the furnace and the breakout of the uranium metal casting. During the latter operation the castings were generally at room temperature. In the crucible cleaning operation, the uranium metal slag was removed from the graphite crucible by vacuum cleaner and by wire brush.

The mass median diameters determined on samples collected by the Laskin impactor during normal uranium unloading and breakout operations were approximately the same as the mass median diameters measured during crucible cleaning. This was to be expected, since the uranium oxide in both operations was formed at the same time and both sets of samples contained graphite dust.

A representative sample of the dust generated during crucible cleaning is shown in Figure 3. This sample was collected on a Millipore filter and the photomicrograph at 500× was made with direct, bright field illumination as collected. The electron micrograph in Figure 3 was made from

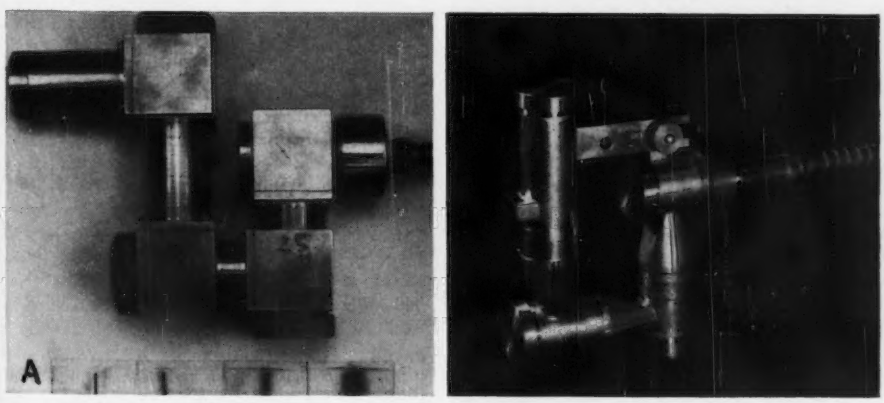

FIGURE 2. A photograph of the LASL model of the Laskin cascade impactor (left) and the LASL modification of the C. F. Casella Company impactor. The Casella impactor has been fitted with a fifth stage filter paper holder and threaded metal end-caps. The glass slides shown with dark deposits illustrate the size and shape of dust collected.

TABLE II

Summary of Measurements on Cascade Impactor Samples Collected in Uranium Foundries

Metal	Operation	Impactor	Total uranium on 5 stages (d/m)	Size Characteristics	
				Standard deviation (σ_g)	Mass median diameter (μ)
Normal uranium	Unloading and breakout	Laskin	734.0	2.06	2.8
	Unloading and breakout	Laskin	64.0	2.3	2.9
	Unloading and breakout	Laskin	188.0	2.5	3.1
	Crucible cleaning	Laskin	553.0	2.7	2.9
	Crucible cleaning	Laskin	910.0	2.5	2.9
	Crucible cleaning	Laskin	204.0	2.4	3.2
	Crucible cleaning	Casella	828.0	3.1	1.9
	Crucible cleaning	Casella	34.0	3.4	2.1
	Crucible cleaning	Casella	736.0	3.7	2.9
	Crucible cleaning	Casella	170.0	2.13	3.2
Enriched uranium	Unloading and breakout	Laskin	44,000	2.6	2.5
	Unloading and breakout	Laskin	1,500	3.5	3.0
	Break press	Laskin	460	4.35	3.6
	Exhaust duct from foundry hoods	Casella 13 samples	154–37,000	2.1–3.83	1.1–2.9 Av. 2.2

the same Millipore filter sample by E. H. Kalmus[6] at Los Alamos. Several fields from this sample were electron micrographed at 2500×, and a total of 853 particles were measured by magnifying the electron micrograph 21 times. The number median diameter (M_g) was found to be 0.08 μ with a standard deviation of 3.2. From these two parameters, the mass median diameter was calculated and found to be 4.5 μ. The number median diameter on another Millipore sample collected during crucible cleaning was measured optically at 450× and found to be 0.75 μ, with a sigma of 2.0. The calculated mass median diameter on this sample was 3.2 μ. This figure compares favorably with the mass median diameters measured with impactors during crucible cleaning shown in Table II.

In Table II, the results given for measurements of samples obtained in the enriched uranium foundry during unloading and breakout are approximately the same as those obtained for samples collected in the normal uranium foundry. The mass median diameter, measured with a Laskin impactor during the breaking of defective enriched uranium casting in the break press, was the highest of any foundry operation. The standard deviation was also the highest, which indicates a very large spread in particle size distribution.

Measurements of 13 samples collected by Casella cascade impactor in the main exhaust duct from the enriched uranium foundry are also shown in Table II. It should be noted that the average mass median diameter for these samples is 2.2 μ, which is approximately 1.0 μ smaller than the mass median diameter of the enriched uranium foundry atmospheric dust. This is due in part to the fact that the larger particles escaped the hood and were thrown into the room, while more of the small particles were captured and exhausted.

MACHINE SHOP

A summary of measurements of cascade impactor samples collected in normal and in enriched uranium machine shops are shown in Table III. It should be noted that the U_3O_8 particles sampled in a uranium machine shop may be due to three sources which affect the size of the particle. When the castings are received from the foundry, they have some residual foundry-formed U_3O_8 dust on the surface which is thrown off during the initial "green" cut. During the machining, in spite of the fact that a water-soluble coolant is used, there are always some chips or turnings burning due to the heat generated by the cutting tool. The amount of burning varies, depending on cutting speed and depth of cut. The chips burn very slowly, giving off an extremely fine uranium oxide fume but always leaving a coarser oxide residue. When the machinist brushes this residue into the coolant pan, he generates a coarser dust in the atmosphere. The water-soluble coolant also causes many of the very fine fume particles to flocculate into larger particles of varying sizes. These factors account for the wide range (0.4 to 3.9 μ) in mass median diameters, as shown in Table III. We have sampled only fume and found that the mass median diameters ranged from 0.4 to 1.0 μ. Measurements of cascade impactor samples collected with little chip-burning ranged from 1.0 to 3.9 μ mass median diameters. However, the average mass median diameter of 2.0 μ obtained for all phases of machining indicates that practically all the air-borne dust is of physiological significance. If we use the average mass median diameter of 2.0 and the most com-

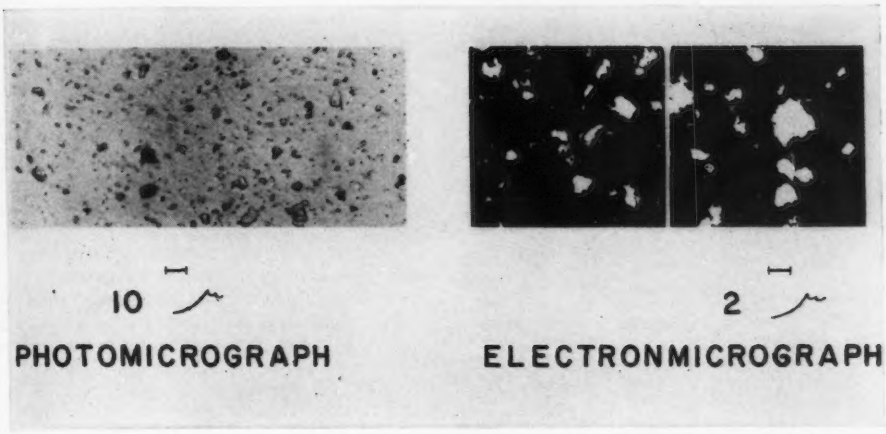

FIGURE 3. Air-borne normal uranium foundry dust collected on a Millipore filter. The above illustrations were made on the same sample.

TABLE III

Summary of Measurements on Cascade Impactor Samples Collected in Uranium Machine Shops

Metal	Operation	No. of samples collected	Standard deviation range (σ_g)	Mass Median Diameter	
				Size range (μ)	Average size
Normal uranium	Machining—with coolant	15	1.9–5.0	0.4–3.9	2.0
	Polishing—wet and dry	6	2.4–4.7	1.8–3.4	2.6
	Milling—dry	2	3.8–3.9	2.3–3.7	3.0
Enriched uranium	Machining—with coolant	12	2.6–4.15	0.9–2.9	1.9
	Exhaust duct—from machine shop	17	1.7–4.37	0.4–1.8	1.1

mon occurring standard deviation range (3.0 to 3.5 for 80% of the samples), we can calculate the number median diameter range, which we found to be 0.02 to 0.05 μ. Adley found that the most abundant size (by count) from an experimentally generated uranium oxide fume was 0.018 μ in diameter.

It may be noted in Table III that the mass median diameter measured in the enriched uranium machine shop was approximately the same as that found in the normal uranium machine shop. However, the size range was not so great in the enriched uranium shop. This can be accounted for, in part, by the fact that one never sees chips or turnings burn in the enriched shop. The results of samples collected in the enriched uranium machine shop's exhaust duct indicate a smaller sized U_3O_8 dust compared with the machine shop atmosphere. The calculated number median diameter of the exhausted dust shows that over 99% of the particles were less than 0.3 μ in diameter, indicating the need for filters capable of removing very fine particles.

MISCELLANEOUS METALLURGICAL OPERATIONS

The results of measurements on cascade impactor samples collected during extruding, welding and heat-treating of normal uranium metal are shown in Table IV. The extruding of normal uranium is done with red-hot billets, which oxidize rapidly. Various inert powders are used to lubricate dies and reduce surface oxidation. The air-borne dust sampled in the impactor represents a mixture of U_3O_8 and foreign powders, which probably accounts for the larger mass me-

TABLE IV

Summary of Measurements on Cascade Impactor Samples Collected at Miscellaneous Normal Uranium Metallurgical Operations

Operation	Impactor	Size Characteristics	
		Standard deviation (σ_g)	Mass median diameter (μ)
Extruding uranium	Casella	2.5	2.9
Extruding uranium	Casella	2.8	3.4
Welding uranium metal	Laskin	3.3	0.6
Welding uranium metal	Casella	3.5	2.6
Heat treating—unsealing can	Casella	4.0	0.9
Heat treating—unloading can	Casella	2.2	2.4

TABLE V

Summary of Measurements on Cascade Impactor Samples Collected During Uranium Oxide Screening and Transfer Resulting from Foundry Crucible Burnout

Sample No.	Impactor	Size Characteristics	
		Standard deviation (σ_g)	Mass median diameter (μ)
1	Laskin	2.4	2.9
2	Laskin	2.4	2.9
3	Laskin	2.2	3.5
4	Laskin	2.1	3.5
5	Laskin	2.7	1.2
6	Laskin	2.7	1.7
7	Laskin	2.3	1.3
8	Laskin	2.7	1.9
9	Laskin	2.9	2.1
10	Casella	3.3	2.1
11	Casella	2.3	1.0
12	Casella	2.3	2.1

Samples 1, 2, 3, and 4 were collected with a Whatman #41 filter paper as the fifth stage. Millipore filters were used in the remaining samples.

dian diameters. This is based on visual observations of the material on the impactor slides at 450×.

The uranium oxide dust formed and generated during the welding of normal uranium metal is similar to that found in a uranium machine shop atmosphere. During the inert gas arc welding, some fume is formed, which we found had a mass median diameter of 0.6 μ. A sample collected during welding and cleaning of weld with a brush had a mass median diameter of 2.6 μ.

Heat-treating of normal uranium castings is done in a large, sealed, steel barrel which holds several castings. The unsealing of the can or barrel with an acetylene cutting torch produced a dust with a mass median diameter of 0.9 μ as shown in Table IV. The unloading operation consists of removal of the oxide-coated castings by hand. The mass median diameter for this operation was 2.4 μ.

FOUNDRY CRUCIBLE BURNOUT

A summary of measurements obtained for samples collected during normal uranium oxide screening and transfer to storage barrels is shown in Table V. This uranium oxide results from a recovery operation where graphite crucibles containing normal uranium slag residue are burned in a furnace. The uranium oxide may be screened before transferring to a storage barrel or it may be transferred directly by pneumatic methods. Metal trays containing normal uranium metal sawings and combustible waste are also oxidized

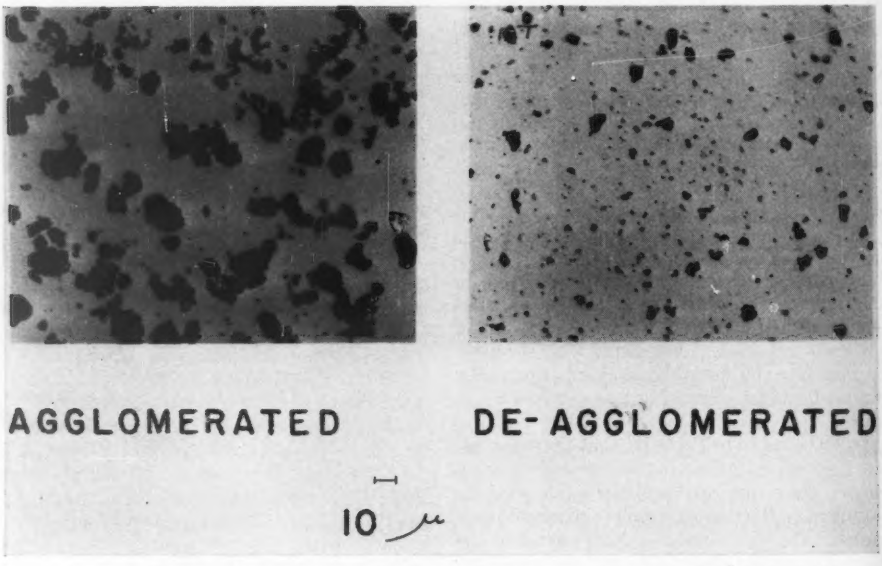

FIGURE 4. Photomicrographs showing agglomerates formed when dispersed on glass slide for measuring and the same dust de-agglomerated at one megacycle and dispersed on glass slide.

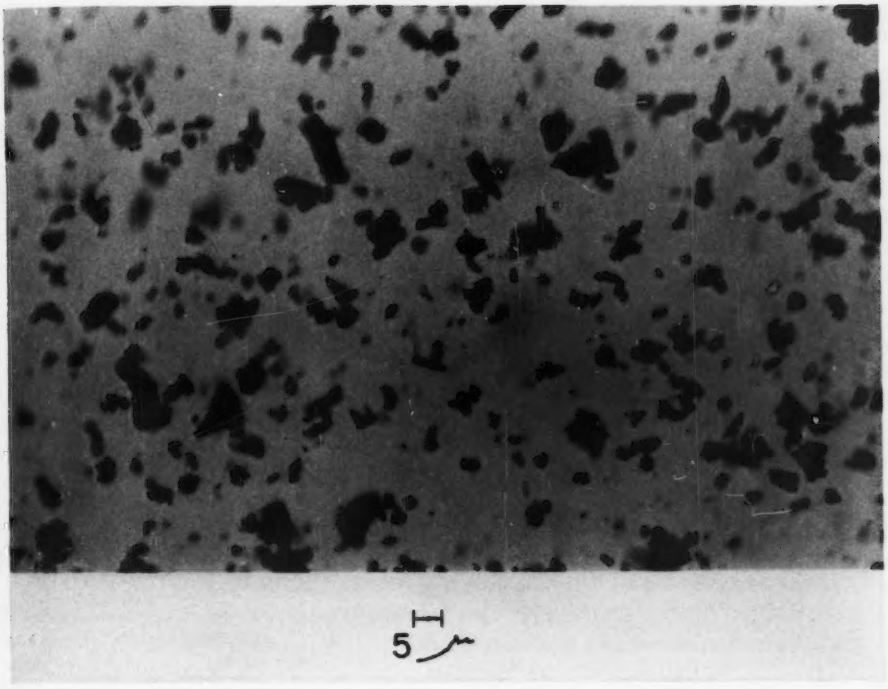

FIGURE 5. Photomicrograph of U_3O_8 dust produced during furnace oxidation of uranium slag. $M_g = 2.2$ microns.

in the furnace and present a dust problem. The measurements summarized in Table V were obtained over a period of years starting in 1950.

It will be noted that the mass median diameter of the first four samples is approximately twice that measured when a Millipore filter was used as the fifth stage. The results of samples collected with the Laskin and Casella cascade impactors (when a Millipore filter was used) are in very good agreement.

Several grams of the normal uranium oxide dust formed in this operation were analyzed and found to contain 2% graphite. This same powder was dispersed on microscope slides and sized optically. A photomicrograph of the dust dispersed in this manner is represented in Figure 4, illustrating in one photograph the agglomerated dust and, in the other, the dust after being de-agglomerated in a solution of isopropyl alcohol at one megacycle for ten minutes. The number median diameter of the de-agglomerated U_3O_8 powder was found to be 0.77 μ, with a standard deviation of 2.75. From these parameters the mass median diameter was calculated and found to be 17.0 μ.

During a U_3O_8 powder transfer operation, the air-borne dust was collected on a Millipore filter. A photomicrograph of the dust as collected on this filter is shown in Figure 5. This air-borne U_3O_8 dust was sized optically (500×) and the number median diameter was found to be 2.2 μ with a standard deviation of 1.8. The calculated mass median diameter was 6.2 μ. The lower limit of the optical microscope was 0.5 μ, therefore, several electron micrographs were made from the same sample (Figure 5) and the size distribution estimated by measuring 570 particles. The number median diameter was found to be 0.85 μ and the calculated mass median diameter was 3.5 μ.

Particle Sizing by Alpha Track Measurement

This method of identification and measurement of alpha-emitting particles is an adaptation of the Leary[7] method. Leary made an autoradiogram by placing an Eastman Kodak NTA (nuclear track alpha) film slide in contact with filter paper or a cascade impactor slide and exposing for a given time and then developing. The tracks on the film resulting from the decay of alpha-emitting particles were then counted.

We have removed the emulsion from an NTA

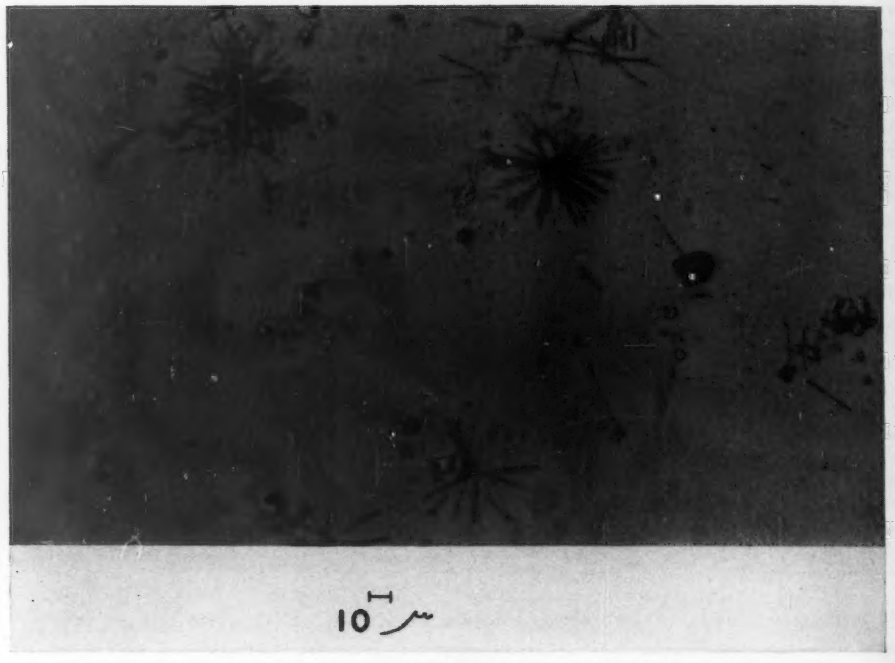

FIGURE 6. Photomicrograph of enriched U_3O_8 particles with alpha tracks and nonradioactive particles collected on cascade impactor slide.

TABLE VI

Estimating Enriched Uranium Particle Size Distribution: Track Count Compared with Optical Measurement of U_3O_8 Particles

Sample No.	Size Calculated from Track Count				Optically Measured U_3O_8 Dust			
	No. of Particles	M_g	σ_g	M'_g	No. of Particles	M_g	σ_g	M'_g
1 Stage 1	255	4.3	1.65	7.5	284	6.4	1.83	16.2
2 Stage 1	192	3.2	1.73	4.8	135	6.0	1.76	13.5
1 Stage 2	144	3.4	1.54	5.7	527	3.3	1.94	8.6
2 Stage 2	163	2.6	1.48	4.1	115	3.8	1.62	6.5

M'_g = mass median diameter

plate by softening for ten minutes in water and stripping with a razor blade. The stripped emulsion was placed over the glass impactor slide or Millipore filter. The Millipore filter is first made transparent with a drop of immersion oil on a clean 1 by 3-inch glass slide. After a predetermined exposure time, the emulsion was developed while still attached to the impactor slide or filter paper. When the emulsion is viewed under a high-dry microscope, the alpha-emitting particles may be identified in place and measured or the particle size may be calculated from the number of tracks arising from individual particles when the length of exposure, decay constant, density and molecular weight of the compound are known. For this calculation, the particles are assumed to be spheres of pure uranium oxide. A photomicrograph of enriched U_3O_8 particles with tracks is shown in Figure 6.

The sensitivity of the track method is limited by the decay constant of the alpha-emitter studied. For example, uranium-238 has a very low specific activity and would require an exposure of 39 months to produce an average of two tracks for one micron particles. For this reason, we have only studied enriched uranium aerosols by this method. Enriched uranium has a higher specific activity, making it possible after a five day exposure to detect particles 1.0 μ in diameter, which produce an average of two tracks per particle. Since the number of tracks is proportional to the cube of the diameter, the method is limited to a fairly narrow range of particle sizes for a single exposure. About 100 tracks per particle is the maximum that can be accurately counted. This corresponds to a 4 μ diameter for a five day exposure period. The range can be extended by exposing different portions of the sample for varying periods of time. Since the radioactive particle

can be identified in place, its size can also be determined optically.

We have exposed 20 cascade impactor slides, representing all four stages, in an effort to calibrate the stages for enriched uranium. To date, our test aerosol consists of workroom atmospheric dust, which is nonuniform from day to day. The particle size of several of these samples has been determined by both alpha track counting and by optical sizing. Alpha tracks are counted on 140 to 500 particles on each sample. A comparison of the two methods is shown in Table VI.

From this table, it is obvious that the two methods do not agree as well as one would wish. The second stage results are in fair agreement since this stage did not have the very large particles found on Stage 1. All the alpha track counts in Table VI were made after a one day exposure. Particles above 7.0 μ in diameter can only be estimated with a one day exposure due to the fact that they produce more than 100 tracks. Additional experiments are underway to improve the accuracy by multiple exposures.

Summary

We have estimated with cascade impactors and by optical measurement the particle size distribution of uranium aerosols that were dispersed during machining and various metallurgical operations. The mass median diameter of air-borne foundry dust ranged from 2.0 to 4.5 μ. The largest mass median diameter range determined by cascade impactors was 0.4 to 3.9 μ in the machine shop. This was expected owing to the nature of the machining on uranium. The number median diameter on uranium fume calculated from the mass median diameter and the standard deviation ranged from 0.02 to 0.05 μ. The number median diameter on U_3O_8 resulting from furnace oxidation of uranium metal slag was measured from electron micrographs and found to be 0.08 μ.

The cascade impactor has definite limitations in its use, although no satisfactory substitute has been available for field use. We have obtained fair agreement between mass median diameter values obtained at specific operations on both normal and enriched uranium. Normal uranium dust may be sized optically, but it would be impossible to size enriched uranium dust optically on field samples due to the small mass of enriched uranium compared with the mass of ordinary atmospheric dust collected on the same slides. The estimation of particle size by nuclear track counting and measurement of alpha track emitting particles is considered the best method for enriched uranium dust.

Our results indicate that mass median diameters obtained with our modification of the Casella impactor show satisfactory agreement with the Laskin impactor data. Differences in the values of the standard deviation have been found in many cases with the Laskin impactor giving better straight line plots and, hence, a more clearly defined value for the standard deviation.

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National Health Forum

THE 1959 NATIONAL HEALTH FORUM was held in Chicago on March 17–19, 1959 by the National Health Council and its sixty-three member organizations. The theme of this year's forum was the *Health of People Who Work—Challenges of Occupational Health*. The challenges were presented in keynote addresses by representatives of government, labor, and management. A special panel discussed the "Expectations of Management Regarding Occupational Health." Then simultaneous group discussions in ten areas were led by special panels. The subject areas were: (1) The placement of workers in relation to their physical and mental capacity; (2) The mental health aspects of work; (3) The environment in which the worker works and lives; (4) Preparations for life after retirement; (5) Health education in the occupational setting; (6) Who pays for what?; (7) Mobilization of resources; (8) Understanding each other; (9) Are occupational health programs worthwhile?; and (10) Where is the manpower to come from?

The Licensee Inspection Program of the U.S. Atomic Energy Commission*

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THE ATOMIC ENERGY ACT OF 1954 specifically directed the Atomic Energy Commission to encourage civilian uses of atomic energy. The Act also placed upon the Commission responsibility for regulating the use of those radioactive materials under the control of the Commission in the interest of health and safety. As a consequence, two new divisions whose purpose is the operation of the regulatory program were organized within the Commission. The Division of Licensing and Regulation is responsible for rule making; that is, formulation and issuance of appropriate regulations and for the issuance of licenses for use of radioactive material and for production and utilization facilities. The responsibility of the Division of Inspection is to determine the state of compliance of licensees with appropriate regulations and conditions of licenses.

Objectives and Status of the Inspection Program

The fundamental objective of the inspection program is to promote safe use of radioactive materials and the safe operation of production and utilization facilities. Specific objectives of the program are the following:

1. To gather factual data on compliance of a licensee with applicable rules and regulations and with special conditions incorporated in his permit or license.
2. In connection with the first objective, to gather information that will assist the Division of Licensing and Regulation in determining whether or not rules, regulations, policies and licensing practices are effective and adequate.
3. To investigate radiation accidents and incidents: (a) to determine the cause of the incident, (b) to determine status of compliance on the part of the licensee, (c) to review the corrective action taken to minimize the danger to the health and safety of the public, and (d) thus to provide information that will assist the Commission to make its rules, regulations, policies, and licensing more adequate and effective.

The program consists of two major parts, corresponding to the two major categories of licensed activities. These are:

1. Use of licensed materials.
2. Construction and operation of production and utilization facilities.

Materials Licenses—Inspection of Operations

In the first category mentioned above activities are licensed for the use of byproduct material, source material and special nuclear material. There are presently approximately 6000 licenses in existence for the use of these materials. Of these, about 5300 involve the use of byproduct material (radioisotopes), about 600 involve the use of source material, and about 100 involve the use of special nuclear material. We distinguish here between the use of special nuclear material as fuel in a reactor, and the use of such material for other purposes. It is the latter use to which we refer in this context.

In the establishment of a system for inspection of materials licenses the first major decision made was that the function would be decentralized to the maximum practical extent. Accordingly, inspection divisions have been organized in eight of the Commission's operations offices. Each office is assigned the responsibility for inspection of licensed users of material in a specified geographic area. Each area contains an integral number of states. The Operations Offices and their areas are listed in Table I. This arrangement provides reasonable geographic proximity of the licensee and the inspector, and allows the establishment of continuing and useful contact both with licensees and interested state agencies. There are now engaged in the inspection functions about forty professional personnel. The immediate goal of the present phase of the inspection program is to develop on the basis of experience appropriate schedules for frequency of inspection of the several kinds of operations and activities. As is well known, the kinds of operations with radioactive materials vary from those involving small and relatively innocuous quantities to those elaborate operations involving large and potentially hazardous quantities of

* Presented at the American Industrial Hygiene Association Annual Meeting, April 18, 1958.

material. The less hazardous activities are inspected least often, allowing the efforts of inspection to be focused properly on those activities more deserving of attention.

A substantial number of licensees are using kinds or amounts of isotopes which themselves present little hazard, or the licensees are operating in a manner that does not require frequent inspection. A smaller number of licensees possess materials which in quantity and kind may be hazardous to workers (or even the public) through accident or misuse. It is this latter group that receives the most attention by the Atomic Energy Commission, both in review of competence before licensing and in inspection after licensing.

Inspection of Production and Utilization Facilities

The problems of inspection of private reactor facilities are more complex than those of the vast majority of operations involving licensed use of materials. The factors that govern the safety of operation arise from two sources, (1) the facility and its material, structural, instrumental and control characteristics, and (2) the people who operate the facility. The first factor defines the potential hazard for the facility and its environs. The second factor determines the extent to which the potential hazard is enhanced, minimized, or eliminated.

The inspection of production and utilization facilities is performed by the Division of Inspection, Washington Headquarters. Inspection personnel officially enter the picture upon issuance of a construction permit. However, the extent and complexity of many reactor projects are such that it is necessary to initiate study when plans and proposals are first presented to the Commission.

Hazards reports are studied in detail, conferences between Commission and licensee personnel are attended, and visits to the designers are made. By this process of familiarization, Inspection personnel become sufficiently acquainted with nuclear hazards aspects of the project that appropriate features of construction can be reviewed intelligently.

During construction, inspections are made to determine that plans and specifications contained in the application for license, and special conditions of the construction permit are being met. As construction approaches completion tests of equipment are reviewed and preoperational integrated test runs are observed. At this stage, the initial trial of operating procedure is possible. It is also at this time that the project evolves from a phase of "preparation of a facility" to that of "the management of a facility."

TABLE I

Geographic Inspection Areas Assigned to the Several Operations Offices

Albuquerque Operations Office	New York Operations Office
Arizona	Pennsylvania
Kansas	Maryland
New Mexico	Connecticut
Oklahoma	Maine
Texas	New York
Chicago Operations Office	Delaware
South Dakota	New Hampshire
North Dakota	New Jersey
Nebraska	Vermont
Minnesota	Rhode Island
Iowa	Massachusetts
Wisconsin	Washington, D. C.
Michigan	Oak Ridge Operations Office
Illinois	Tennessee
Ohio	Kentucky
Indiana	Virginia
Hanford Operations Office	West Virginia
Washington	Mississippi
Oregon	Louisiana
Alaska	Arkansas
Idaho Operations Office	Missouri
Utah	Puerto Rico
Colorado	Savannah River Operations
Wyoming	Alabama
Idaho	Georgia
Montana	Florida
San Francisco Operations Office	South Carolina
California	North Carolina
Nevada	Panama
Hawaii	Virgin Islands

On the basis of such tests and trials of procedure, and on observation of the operating organization, its discipline and familiarity with procedure, recommendation to the General Manager regarding issuance of a license for the operation of the facility is made by the Division of Inspection. When a license for the facility is granted, initial start-up and operation are observed. During this period, characteristics of the reactor and auxiliaries and the effectiveness of organization and procedure are noted and evaluated.

It is at this stage that regulations and conditions of the license can first be evaluated through actual experience in the operational safety of a particular installation. Periodic inspection visits are made to the facility, and the findings and recommendations are transmitted to the General Manager and to interested divisions in the Commission organization.

Inspection Personnel

A second major decision made in the formative stages of this program was that in order to meet the fundamental objective of the program mentioned above, inspection personnel must be knowledgeable and experienced in the handling

of radioactive materials and control of radiation, and in the practical aspects of design, construction and operation of reactors. The shortage of trained and experienced scientific and technical personnel in these fields is thoroughly recognized. The Division of Inspection finds also that the recruitment of such personnel is a slow and difficult process. However, it is the firm view of the Commission that the quality of the inspection effort is of more lasting importance than quantity.

Radiation Incidents

In May of 1957, the Commission formally approved an amendment to *10 CFR Part 20, Standards for Protection Against Radiation* requiring that certain classes of radiation incidents be reported to the Commission. In order that licensees may have a proper and reasonable frame of reference on this subject, three kinds of radiation incidents are defined. The definition of the first kind implies an accident of such severity that an immediate report and institution of remedial action is required. The other two are in order of decreasing severity, and the reporting and investigative requirements therefore are less stringent. Procedures for investigation of these incidents have been formulated by the Division of Inspection and approved by the Commission.

Observations

1. Inspection experience indicates that the vast majority of licensees are exercising serious and competent effort to meet their responsibility of protecting the health and safety of employees and the public.
2. In the incidents that have occurred to date, prompt action by the licensees, often with advice and assistance of the AEC, has avoided serious consequences or injury.

Viewed in relation to the total present activity, the number of incidents and circumstances surrounding these incidents does not warrant particular worry or alarm. There remains, however, much to be learned by licensees and the Commission of how to improve operational safety and to reduce further the probability of and consequences of radiation incidents. One of the major objectives of the inspection function noted above is that of extracting all possible pertinent information from radiation incidents and abnormal situations so that such experienc may be applied to the improvement of the regulatory program, and to the improvement of operating principles and procedures by licensees.

Advanced Degree Program

THE DEPARTMENT OF INDUSTRIAL MEDICINE AND HYGIENE at Wayne State University, Detroit, Michigan has announced a course of study leading to the Master of Science degree in Industrial Hygiene. The program was initiated on March 16, 1959. Courses will be given on a quarterly (12-week) basis. Two plans of study, each requiring 32 credit hours, are available for obtaining the degree.

Required and elective subjects cover the principles of industrial hygiene, toxicology, control methods, sampling, analysis, public health, statistics, lighting, noise, air pollution control, radiologic health, and research or essay projects. For complete information write to Ralph G. Smith, Assistant Professor, Department of Industrial Medicine and Hygiene, College of Medicine, Wayne State University, 1401 Rivard Street, Detroit 7, Michigan.

Evidentiary Problems in Proving Radiation Injury

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RADIOACTIVITY AND IONIZING radiation are not new. Neither is radiation injury. More than 50 cases of x-ray injury were reported as early as 1902. More than a hundred cases have reached our courts. Some radiation injury cases have been settled out of court and many suits have been barred by the statute of limitations. Most legal actions have been malpractice suits based upon injury from diagnostic or therapeutic uses of x-rays and radium. A small number have resulted from industrial applications of x-rays and radioactive materials. The potential for radiation injury is greatly magnified today. More than 5000 firms are using either reactor produced radioisotopes or naturally occurring radiomaterials. More than 125,000 x-ray machines are now in use.

Legal actions based on radiation injury pose many difficult evidentiary problems which are of interest to the technical expert as well as the lawyer. The technical expert will play an important role in any litigation since, generally, the legal profession has not acquired the language or an understanding of the technology. In any personal injury suit a plaintiff must show: (1) that the defendant owed a duty to the plaintiff to exercise a certain degree of care, (2) that the defendant failed to exercise that degree of care, and (3) that the defendant's lack of care resulted in damage to the plaintiff.

One of the most difficult problems is to prove actionable radiation injury. The ordinary rules of evidence and expert medical testimony will apply in proving that a diseased condition exists —for example, leukemia or lung cancer. Many difficult problems may be encountered in the next step, proving that the diseased condition or injury is due to ionizing radiation for which the defendant is responsible.

The first problem in proving that a disease or injury is due to radiation results from the fact that diseases associated with radiation are not specific to radiation:

a. Leukemia, for example, will develop in a small percent of the population independent of any exposure to significant levels of radiation.
b. Skin cancer may be due to radiation, ultraviolet rays, or a number of carcinogens.
c. Blood dyscrasias may be due to radiation, antibiotics, heavy metal poisoning, or a number of other causes.

Another problem is the long latent period, depending upon the radiation dose, between the time radiation is received and the manifestation of clinical symptoms.

a. In the case of the radium dial painters the latent period ranged from three to 15 years.
b. Lung cancer in miners of radioactive ores developed over a period of 17 years.
c. Skin cancer has manifested itself after a period of 50 years.
d. Third degree x-ray burns have become malignant after 10 to 12 years following the initial burn.

The delayed effects of radiation are important in several respects from a legal viewpoint:

a. The cause of action may be barred by the statute of limitations. All of the radium dial painters who instituted suit in the state of New Jersey were barred by the statute of limitations.
b. The injury may never be associated with the earlier employment if several years have elapsed before symptoms develop.
c. Witnesses and records may not be available or the witness' memory may be dim. It is important, therefore, to keep one's records and keep them for a longer period than the statute of limitations. It is to be noted that the doctrine of equitable estoppel may be interposed to prevent a defendant from pleading the statute of limitations under certain factual situations.

Radiation injury may result from internal exposure from radioactive materials deposited in the body or external exposure from radiation emitters. If internal exposure is involved, it may be possible to establish a causal relationship between disease and radiation if deposition of radioactive materials in the body can be demonstrated:

a. Radon in the breath may be measured if radium is deposited in the body.
b. Sensitive tests on excreta may indicate the presence of certain isotopes.
c. Radiographs may also indicate radioactive substances deposited in the bone. It is to be

noted, however, that large quantities of radiomaterials with a short biological half-life may have been taken into the body and excreted so that a few months or years later it would not be possible to demonstrate such materials in the body.

A more difficult problem may be encountered in proving that a person received an injurious external dose of radiation. This may be somewhat simplified if suitable personnel monitoring instruments were worn by the person. Although dosimeters have distinct values, dosimeter readings may be of little value to a defendant unless worn in conjunction with film badges. A dosimeter may discharge accidentally. Even though the discharge is due to ionizing radiation, the ordinary dosimeter may not establish the actual dose received. If its maximum reading is 200 milliroentgen and it is discharged completely, an unanswered question arises as to whether the dose was 201 mr or much greater.

Film badges, on the other hand, can be a defendant's most persuasive evidence that the plaintiff was not exposed to injurious levels of radiation. The film itself should be available for introduction into evidence. Retention of the film will also permit verification of the reading at a later date. It is important, however, that film badges be issued, worn, and developed under known, controlled conditions. The party relying on such film badges should be prepared to defend their accuracy. Opposing counsel may frame 30 to 40 questions in an attempt to impeach the value of such records. The following are examples of questions that may be raised:

How was the film positively identified as issued to and worn by plaintiff?

What was the sensitivity range of the film?

Was the film compared to a control film, exposed to known amounts of equivalent radiation?

Were the film and control developed together in the same developer?

What was the temperature of the developing solution?

What was the developing time?

Was the film estimated by eye or read on a densitometer?

How was the densitometer zeroed?

What material was used to filter out the low energy gammas?

Where was the film to be worn?

Was the film in fact worn in such position and how do you know?

Could the film have been shielded while part of the body was receiving high level dosage?

Notwithstanding the numerous questions that may be raised, a good film badge service may be exceedingly valuable from a legal viewpoint. In any event the possible legal value of personnel monitoring instrumentation should always be borne in mind. Such instrumentation may be advisable in some cases where not justified for technical reasons alone.

Another factor to be borne in mind is the fact that a plaintiff may attempt to introduce evidence showing that the defendant has violated a safety statute. If it can be shown that the defendant has violated a safety statute or regulation which was intended to protect persons such as the plaintiff, and that such violation caused or contributed to plaintiff's injury, a case is made out of negligence per se. This usually means that the plaintiff will prevail in the legal action. It is important to keep in mind the possible civil effect of violating regulations in addition to any possible fine or penalty. In addition to stringent regulations of the AEC and federal transportation agencies, it is to be noted that seven states now have fairly broad regulations in this field and over half have some regulations that may affect one's operations.

Another evidentiary problem from a defendant's viewpoint is the fact that the plaintiff, under certain factual situations, may have the benefit of an inference or presumption of negligence. This will require the defendant to give a good explanation and offer evidence to overcome the probative effect thereof. In many of these cases evidence may not be readily available to either plaintiff or defendant. In any event it is particularly important to the defendant in such cases to have the very best of records. The burden of proof never actually shifts to the defendant but the same effect may be achieved in actual practice.

It is not possible in this brief article to do more than touch lightly upon some of the evidentiary problems that may arise in a legal action founded upon radiation injury. In brief summary, however, a few suggestions may be repeated:

1. Keep full and complete records of safety procedures and detailed accounts of any radiation incidents.
2. Maintain the records beyond the apparent statute of limitations.
3. Subscribe to a good film badge service and retain the films. Maintain records of how they were issued, identified, and worn. Be prepared to defend their accuracy.
4. Comply with pertinent regulations.
5. The best solution to a legal problem is anticipate it and avoid it—keep in close touch with counsel.

Radiation–A Photofluorographic Study

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FOR MANY years the photofluorographic x-ray unit has been used in the early detection of tuberculosis and allied chest conditions. This unit, popularly known as the chest x-ray unit, has been a dynamic tool in the reduction of the prevalence of lung diseases. It is economical, fast, painless, and capable of screening several hundred persons per day. It has the advantage of being portable and almost comes into the home.

With a greater understanding of the effects of ionizing radiation, maximum permissible exposure and dose levels have been established.[1,2] These limits are designed primarily for the protection of the operating technician. Since no records are kept of the general public's radiation exposure, these limits do not apply to it. However, 10 per cent of the occupational limits has been regarded as the maximum for those persons not occupationally exposed.

In an effort to determine the radiation exposure of the general public, several photofluorographic installations were studied. The parameters of these studies included evaluation of direct x-ray beam, gonadal exposure of subjects, and the exposure of persons in the vicinity of these units.

Methods of Study[3, 4, 5]

Dosimeters with a range of 0–200 milliroentgens for x-ray or gamma radiation were used to measure approximate gonadal exposure of subjects and were used principally in area monitoring. These dosimeters were reported by the manufacturer to be energy dependent within 5 per cent from 250 Kev to 1.2 Mev.

For gonadal region exposure, two dosimeters were tied to a stout cord and the cord was placed around the subject like a belt. By having one dosimeter at the subject's back and an additional dosimeter in front of the subject in the gonadal region, the amount of radiation could be measured before and after penetration of the x-ray beam.

Area monitoring consisted of evaluating ratiation fields at various points in the adjoining space. In all instances a subject was in the beam of the photofluorographic unit when the measurement was made. A new ion chamber survey meter, calibrated for time-response ratio, was used for area monitoring. In instances where the x-ray unit's operating time was very short due to the use of fast films, dosimeters were placed at points of measurement and were read following several exposures.

Direct beam measurements were made with a pre-calibrated 0–20 roentgen dosimeter. The x-ray beam was directed from the grid or screen so as to by-pass the photoelectric timer and to permit a full two-second exposure evaluation.

Mechanism of the Production of X-rays[6]

X-rays are produced when high velocity electrons impinge upon target atoms. The target may be either a heavy metallic element or freely moving molecules of a gas within a discharge tube. When an electron strikes a target atom, its energy is expended in the production of x-rays, in the formation of heat, and in the production of light. The high velocity of the electron is achieved by placing a large electric potential between the cathode (the electron source) and the anode (the target material).

The voltage and the cathode-to-anode flow, measured in milliamperes, determine the intensity of the x-ray beam. Since very few electrons give up all of their energy in a single encounter with a target atom, a spectrum of x-ray wavelengths is produced. The minimum wavelength produced becomes shorter as the votage is increased. The shorter the wavelength of the x-rays produced, the greater is their power to penetrate matter. As the tube current is increased, the flow of electrons is increased. This results in a greater quantity of x-rays of a given penetrating power.

The long wavelength x-rays are less penetrating and are of no practical value to the diagnostician. They seldom reach the film because they are absorbed by tissue and bone. They may be removed by placing filters of suitable thickness between the cathode tube and the subject. Aluminum is a good material for this purpose.

In order to limit the radiation exposure of subjects by reducing the area exposed, cones, shutters, and diaphragms are also appended to the x-ray units.

An important factor in reducing unnecessary operator exposure is that of establishing adequate

distance from the tube and the patient. The intensity of radiation varies inversely with the square of the distance from the source. By doubling the distance from a source of radiation, the exposure rate will be reduced by a factor of four. By tripling the distance, the exposure rate will be reduced ninefold.

If shielding is interposed in lieu of distance, the radiation intensity will also be reduced. The thickness and the type of material are the controlling factors. Although there are slight differences in the amount of scatter, it may be stated generally that the reduction of intensity of x-radiation will remain approximately the same regardless of the position of the shield; i.e., whether the shield is closer to the source or closer to the subject.

Stray Radiation[3, 6]

As a collimated beam of x-rays passes through the air and tissue, some of the rays are scattered. This scattering can cause exposure in areas thought to be protected. In addition to scatter, the materials in the path of the beam may become ionized. In this process, if enough energy is imparted to an orbital electron of an atom (0.51 Mev), the electron will be ejected. The ion pair thus produced, the residual of the atom and the electron, will then recombine with other ions to form stable atoms. During the recombination, the excess energy will be expelled. This excess energy may be in the form of x-rays. Thus, the material becomes a secondary source of x-rays while the primary beam is directed toward it. The tissue may be damaged during its ionization.

When an x-ray passes through a person, more of the radiation is absorbed by the dense areas of the body, such as bone and teeth, than is absorbed by soft tissue. When a fluoroscopic screen or film is placed opposite the person this variation in density is evident.

The Photofluorographic Unit

The principle of operation of the photofluorographic unit is the use of a camera. The subject is placed between an x-ray tube and a fluoroscopic screen or grid. A camera is mounted behind the screen. As soon as the screen glows, the camera shutter is opened, and a photograph is made. A typical arrangement of the unit is diagramatically presented in Figure 1.

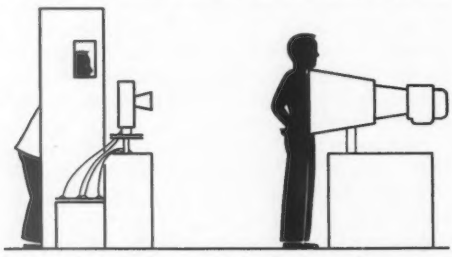

FIGURE 1. A Typical photofluorographic unit.

The shutter speed of the camera is predetermined by the type of film used. In general, a timer switch is set for two-seconds' duration, but a built-in photoelectric cell terminates the x-ray beam when the film in the camera has had sufficient exposure. This exposure can be of the order of one-half second when fast films are used.

The radiation dose received by the individual varies with the tube voltage, the total filtration of the beam, the milliamperage. the distance between target and subject, and the exposure time.

Another important factor is the amount of coning present on the unit. While this will not reduce the beam intensity per se, it will reduce the area being irradiated. Since the area exposed is reduced, the total dosage to the patient will be reduced.

While the target-to-subject distance varies greatly due to variations in patient thickness, most photofluorographic units maintain a target-to-grid distance of approximately forty-one inches. Table I[7] incorporates the voltage, amperage, time, and filtration factors at the normal photofluorographic distance in order to estimate the direct beam exposure to subjects. Most units have an inherent filtration equivalent of one-half to one millimeter of aluminum, and these amounts are given in the table. Additional filtration is beneficial in subject exposure reduction, and the U. S. Public Health Service has found that three millimeters of aluminum can be used before any change in operating technique is required.

Table I may be used as follows: A photofluorographic unit was in operation for one second at 100 kilovolts and 150 milliamperes. When a total

TABLE I

Exposure Rate in Air at 41-Inch Target-to-grid Distance[7]

Peak tube voltage (kilovolts)	Exposure rate in air at grid (without scatter) (milliroentgens per milliampere-second)	
	½ mm aluminum total inherent filtration	1 mm aluminum total inherent filtration
80	11.2–16.8	6.9–9.6
85	12.8–19.2	8.0–12.0
90	14.4–21.6	8.8–13.2
95	15.2–22.8	11.4–15.6
100	16.8–25.2	12.0–18.0

inherent filtration of one millimeter of aluminum was found, what was the total dosage delivered in air to the fluoroscopic screen area? Under "Peak tube voltage" find 100 kilovolts. In Column 3 find 12.0–18.0 milliroentgens per milliampere-second. Since there were 150 milliamperes for one second, there are 12 × 150 to 18 × 150 or 1800 milliroentgens to 2700 milliroentgens per exposure. In practice, the average quantity found in an old unit under these conditions was of the order of 2200 milliroentgens, or approximately the mean of these two values.

Discussion—Public Health Aspects

Radiological health implications regarding the use of photofluorographic units when used in mass chest x-ray surveys are unnecessary radiation exposure to the subject, to technicians and clerical personnel, and to other persons standing near the units. Handbook 59[1] of the National Bureau of Standards lists criteria for occupational exposure. This is reproduced in Table II. There is no definite limit for non-occupational exposure.

Recent proposed changes of these maxima* state, "The maximum permissible dose to the gonads for the population of the United States as a whole from all sources of radiation, including medical and other man-made sources, and background, shall not exceed 14 million rems per million of population over the period from conception up to age 30, and one-third that amount in each decade thereafter. Averaging should be done for the population group in which cross-breeding may be expected". The occupational accumulated dose, in rems, at any age is "equal to five times the number of years beyond age 18, provided no annual increment exceeds 15 rems. Thus the accumulated maximum permissible dose = 5 (N–18) rems where N is the age and greater than 18. This applies to all critical organs except the skin, for which the value is double".

Gonadal Exposure

An important consideration regarding unnecessary radiation reaching the subject is that amount which reaches the gonads. The actual amount of genetic damage which results from any given radiation exposure is not definitely known. The literature on this subject is inconclusive, and quantitative data estimates have a large variance. Even though the numerical values may differ, it should be pointed out that there is no fundamental disagreement. Geneticists believe that all unnecessary radiation is harmful.

The National Academy of Sciences in their summary reports of the biological effects of atomic radiation state, "This report recommends

TABLE II

Maximum Permissible Total Weekly Doses in Critical Organs to External X-radiation*

Condition of exposure	Weekly doses in significant volume in region of highest dose rate in milliroentgens				
	Adult age	Skin	Organs	Gonads	Lens of the eye
Whole body	under 45	600	300	300	300
	over 45	1200	600	600	600
Hands and forearms	under 45	1500	300	300	300
	over 45	1500	600	600	600
Feet and ankles	under 45	1500	300	300	300
	over 45	1500	600	600	600
Head and neck	under 45	1500	300	300	300
	over 45	1500	600	600	600

* The National Committee on Radiological Protection in N.B.S. Handbook 59[1] Proposed revision of these maxima would reduce these levels considerably.

that the general public of the United States be protected by whatever controls may prove necessary, from receiving a total reproductive lifetime dose (conception to age 30) of more than 10 roentgens of man-made radiation to the reproductive cells. Of this reasonable (not harmless, mind you, but reasonable) quota of 10 roentgens over and beyond the inevitable background of radiation from natural causes, we are now using on the average some three or four roentgens for medical x-rays. This is roughly the same as the unavoidable dose received from background radiation. It is really very surprising and disturbing to realize that this figure is so large, and clearly it is prudent to examine this situation carefully. It is folly to incur any x-ray exposure to the gonads which can be avoided without impairing medical service or progress".

In order to determine an order of magnitude for gonadal exposure during photofluorographic x-ray, a study of exposure of approximately seven hundred individuals was made. This study was made using x-ray units in relatively fixed positions in hospitals, units mounted in buses, and mobile units stationed at public buildings and at industries. The procedure involved the use of 0–200 milliroentgen dosimeters (described above). Using twine as a belt, one dosimeter was placed on the subject's back, just below the area to be x-rayed, and another dosimeter was placed at the front of the subject. After many such determinations, the procedure was modified in that one dosimeter was hung from the lower part of the grid. The dosimeters were read following each exposure. The exposures found at the point of measurement are reported in Table III.

There was a very large standard deviation from

TABLE III

Exposures Found at Point of Measurement of Persons Receiving Photofluorographic Chest X-rays

Point of measurement	Milliroentgens per average photofluorographic examination	
	Dosage	Range
Back of male subjects, before penetration	11.0	0.0–101.0
Back of female subjects, before penetration	29.4	2.0–168.0
Back of male and female subjects, before penetration[a]	18.0	
Front of male and female subjects, after penetration (exit dose)	1.0	0.0– 8.8

[a] Data resulting from mixed group of subjects, without differentiation for sex. These data were obtained at the beginning of the study

these average values. This variance was due in part to the automatic timing device used in the units and in part to the confining qualities of the cones. The actual amounts of radiation reaching the reproductive organs vary with the thickness of the subject (especially in the male) and the distance between the point of penetration and the reproductive organs. It should be pointed out that, in all probability, most of the radiation was absorbed in the first few centimeters of tissue.

There was a greater range in the female subjects as recorded by dosimeters placed on the back, than there was in the male. There was no apparent correlation between the size of the female subject and the dosage. No explanation for the discrepancy was apparent during this study. It may be the result of differences in bone structure.

Adequate cones, capable of confining the beam to the area of the lung and thereby protecting the gonadal region of subjects, are an important consideration in reducing unnecessary radiation exposure. For large chest films, the adequacy of the cone may be determined by observing the corners of the film. If there are unexposed corners, the cone is effective. Such study cannot be made using photofluorographic film. However, a reliable test may be made by placing a strip of a discarded fluoroscopic screen at the edge of the grid and observing whether it glows when the unit is energized. The strip should glow only in the area under observation. If it glows beyond this area, a more confining cone should be used.

Area Study

A major problem is that of exposure of persons to stray radiation in the area of the unit when it is activated. An area monitoring study using dosimeters and an ionization chamber survey instrument indicated that clerical personnel were frequently overexposed. Clerks are often stationed in close proximity to the unit in order to complete file cards identifying individuals x-rayed. Their desks, even though located behind the unit, are generally beyond the area protected by the unit's operational shield. Determinations at several locations indicated a range of 0.25 to 1.00 milliroentgen per average photofluorographic x-ray. This may become a significant overexposure to the clerks since several hundred x-ray exposures may be accomplished each day.

The operator is protected by means of a shield which separates the control panel from the x-ray tube and subject. Because of carelessness he may not always make full use of this protection and may needlessly expose part of his body. Radiation levels exceeding five milliroentgens per average exposure were found along the edge of this shield at several installations.

The third group exposed to stray radiation are those in a waiting line ready to be x-rayed. In one instance, where a large number of people were crowding the unit, a 0–200 milliroentgen dosimeter was placed in the shirt pocket of one of the subjects. As he approached the unit, his cumulative dosage was determined. During this time he was exposed to stray radiation from sixteen exposures and had traveled a distance of about twenty feet. He had received an exposure of 18 milliroentgens during this time. Most of this exposure resulted from the line being permitted to move close to the front of the unit where the stray radiation was significant.

Should the unit be installed in a building with a low ceiling and walls highly reflective to x-rays, the quantities of stray radiation are greatly increased. Such an installation was recently studied and radiation levels exceeding 0.6 milliroentgen per maximum (two second) exposure were noted at the operator's position. The exposure of clerical

TABLE IV

Stray Radiation Levels at the Exterior of a Portable X-ray Unit Mounted in a Bus

Location	Distance from x-ray unit (feet)	Amount of stray radiation (milliroentgens per 100 exposures)
Sidewalk, opposite exit	9	1.05
Sidewalk, opposite exit	23	0.09
Front of bus	12	0.02
Street side of bus, opposite exit	6	0.08
Rear of bus	18	0.03

personnel at twenty feet from the unit was of the order of 0.2 milliroentgen per maximum exposure.

Bus Photofluorographic Units

In the bus-type units, exposure of persons in the vicinity for considerable periods of time, such as policemen and news vendors, may also be important. Measurements, using an ionization chamber survey instrument and 0–200 milliroentgen dosimeters, are reported in Table IV. It should be noted that the bus itself offers considerable shielding. There is also a great reduction of exposure with distance. Since this reduction is greater than the intensity expected by calculation, it may be concluded that the secondary radiation is composed chiefly of long-wavelength x-rays.

Regarding technician exposure, two technicians are generally employed on these units. One remains at the controls and the other, after placing the subject at the grid, retires to a small shielded area. There are occasions when the x-ray unit is activated before the second technician reaches the safety of the second shield. On these occasions the second technician is needlessly exposed to radiation.

General Recommendations

The following precautions should be observed in the operation and maintenance of photofluorographic units:

1. Adequate cones should be used to confine the primary x-ray beam to the dimensions of the fluorescent screen. Fast films should be used to reduce exposure time. Filters should be added in order to remove needless exposure to soft rays.
2. Operators should remain completely behind the protective barrier when the unit is energized. The lead glass window should be used to view the subject. Controls should be operable only from behind this barrier.
3. Film badges or dosimeters should be worn by operating personnel in order to estimate exposure.
4. Clerks should be at least twenty-five feet behind the operational shield, or should be stationed behind a protective barrier.
5. Interlocking switches operated from behind the secondary shield of bus x-ray units should be provided. This would prevent the operation of the unit until the second technician is shielded.
6. The waiting line should be defined by portable barriers or floor markings to prevent crowding at the front of the unit.
7. The unit should be positioned in such a manner as to prevent exposure to occupied areas.
8. Units not installed in buses should be housed in large areas so that as much distance as possible be maintained between the unit and walls. Adequate wall shielding should be provided if distance is not possible.

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Radiation Hazards Associated with Dental Roentgenography*

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THE ADVENT of the atomic era has brought forth a large number of articles in lay journals and newspapers dealing with radiation. Attention of the public has been focused on radiation largely because of atomic bomb fallout and the effects it may have on large masses of people. Their perspective has therefore been somewhat broadened to a point where "radiation" and "danger" have coherent connotations. These terms, which have varied degrees of significance to radiologists, physicists, chemists, biologists, etc., have now become a household byword. People who heretofore thought they had little concern, have now developed an awareness of radiation, and it is not so surprising that questions have arisen where individual fears have been expressed in no uncertain terms, almost to a point of hysteria.

It is the purpose of this paper to report on a common source of radiation upon which more attention should be centered since, in contrast to fallout, it can provide an overwhelmingly greater hazard. The reference is to diagnostic-x-radiation, and specifically to dental roentgenography.

Our attention was originally focused on dental roentgenography because it is probably the largest single source of radiation to which large numbers of people are exposed throughout their lifetimes. Many of our own personnel at the University of California who inadvertently wore their personal film badges or who requested same for monitoring themselves during oral roentgenography, returned their film badges with positive exposures from the scattered radiation.

For several years we have been checking dental x-ray machines in the San Francisco area of California at the request of the dentists. Some of these requests were made because of questions asked of the dentist by his patients regarding the nature of the radiation and the dose received. Many of the dentists themselves were worried because of the publicity given to the hazards of radiation.

* This work was done under the auspices of the U.S. Atomic Energy Commission Contract No. W-7405-eng-48.

Some of our findings have been indeed surprising. It is difficult to believe the fact that some of the users of these machines are still in the "stone-age" with regards to understanding the potential hazards of their machines. Fortunately, most of the new models of x-ray dental units have radiation limiting devices such as long cones, lead diaphragms and filters integrally built into the machine so that little more is required to be done with them. However, since there are about 65,000 units or more of vintage 1953 and earlier, we would feel remiss not to point out the simple modifications that one can use to turn a potentially hazardous machine into a more typically safe diagnostic unit.

For those unfamiliar with the x-ray sources from diagnostic x-ray units, a brief description might be in order. A fast stream of electrons from a cathode filament is allowed to impinge on a tungsten target. When these electrons are decelerated, energy in the form of x-rays is radiated. The radiation comes out in all directions, but because the target itself provides a shielding effect, it is confined for the most part to a cone. The x-rays are a source of a continuous energy spectrum from zero to the maximum applied energy (usually 55–65 kev).

After surveying some typical diagnostic machines the following observations became quite evident in many cases:

The patient was being exposed to more radiation than was necessary to produce a good diagnostic roentgenogram.

The dentist or technician taking the x-ray picture was using faulty techniques which in some cases could produce deleterious effects.

People in areas outside the diagnostic room were subjected to unnecessary exposure from the scattered radiation beam.

If one were to describe an installation that was characterized by the above shortcomings, it would look something like this:

Collimation of the primary beam is poor.

Filtration is inadequate.

The tube housing affords poor protection, especially at the sides.

A slow-type film is used.

The timer cord is so short that the operator is in a high exposure radiation field and no shielding is provided him during this time.

Areas adjacent to the diagnostic installation are not usually shielded against stray radiation.

Measurements made of the primary beam in an office having the aforementioned criteria will be as high as from 75 to 270 R/min, depending on the type of x-ray unit. The exposure rate to the operator could be several R/hr and levels as high as 500 mR/hr have been observed in reception and waiting rooms.

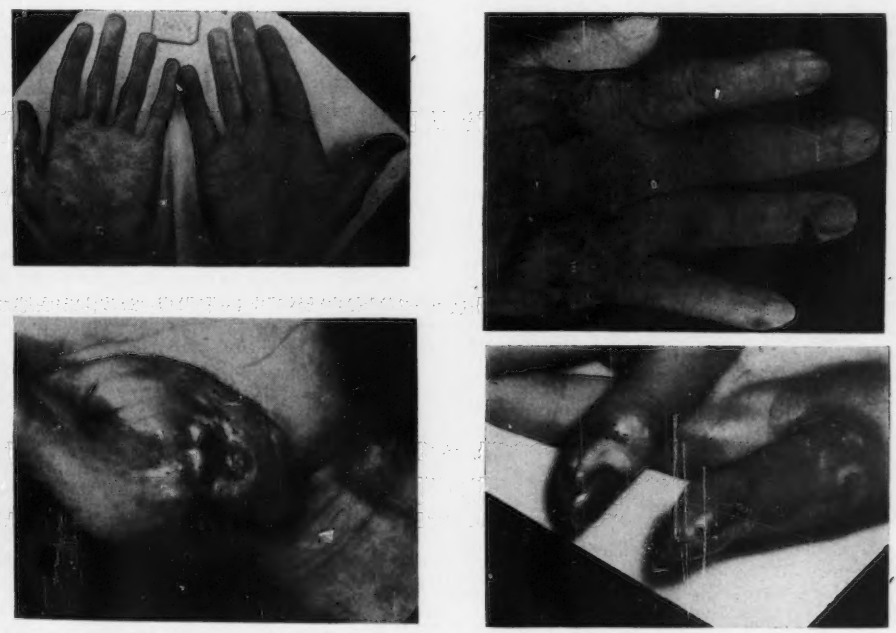
The picture can only be complete if the exposure doses of these machines are enumerated. The average full mouth examination can entail the taking of from 16 to 36 exposures plus retakes depending on techniques. The total time involved for a full mouth examination can run from 45 to 90 seconds again depending on the technique used. This means that under the worst conditions certain areas of the patient's skin can receive a dose that might be as high as 75 R. It is also possible that this patient could undergo an examination of this type at least once per year or perhaps more often.

What of the biological effects to a patient undergoing examination on a hazardous machine? Some hematological studies made by Dobson and Chupp at the University of California showed a significant depression in lymphocyte count after a full mouth examination was given to several patients.[1]

Although apparent recovery was later observed this seemingly reversible insult cost something perhaps in terms of some irreversible bodily functional structure. This feeling has been expressed by many in the field of radiobiology and medical physics and is shared by us. In any event a precious check in our life "checkbook" may have been cashed.

What of the dentist or technician? The technique used by some dentists has been to hold the film or tube head in position during the taking of the x-ray picture. This has indeed been costly as Figures 1–4 indicate. These figures show radiation injury to the hands of dentists and dental technicians.

One of our dental consultees was so impressed with x-ray hazards that he established a Committee for X-ray Safety amongst a dental association of which he is a member. In October 1956 this committee sent out to its members a questionnaire pertinent to the x-ray equipment



FIGURES 1 through 4. Radiation effects received from faulty diagnostic x-ray procedures. (Courtesy of Gordon M. Fritzgerald, D.D.S., University of California, Medical Center, San Francisco, California.)

they used. Only 50 of 85 questionnaires were returned. One of the dentists had a machine with the following characteristics—short cone, no filter and a 3.75 sec exposure. This machine would be producing an exposure dose rate of 7 R per film. The following table shows the results of a subsequent survey made by the same dental association one year later after the results of the first survey were tabulated, evaluated, and returned to the membership (106 out of 125 replied):

	Yes	*No*
Have you made any changes in your x-ray equipment and/or procedure since our last questionnaire?	63	40
Do you have at least 1½ millimeters of aluminum filter?	98	4
Do you have a lead diaphragm?	93	6
Do you use a fast film?	100	2
Do you use the recommended long development procedure?	86	13
Have you had a professional survey made of your equipment?	28	77

Professional surveys seem a luxury to many. However, our feeling is that public relations and the know-how gained by speaking to professional consultants more than offsets the expense.

Now, what measures can be taken to insure a minimal exposure to the patient, and operator, and yet maintain a satisfactory roentgenogram. They are simple.

(1) Filters of at least 1.5 or 2 mm of Al should be used for the primary x-ray beam. The purpose of this filter is to harden the beam by absorption of the soft components of the continuous x-ray spectrum which do not contribute to the darkening of the film, but merely produce skin and superficial tissue insult. It has been clearly demonstrated that the patient's dose can be reduced by a factor of five or more by this simple expedient and yet one can maintain optimum diagnostic definition.

(2) Field limiting cones and diaphragms should be used. These will allow collimation to be limited to the area to be radiographed and will thus eliminate unnecessary exposure of large areas of skin.

(3) Fast film and optimal developing should be used.

(4) Higher kv and lower milliamp-seconds will mean better diagnostic x-ray films with less radiation for the patient and dentist or technician.

(5) A long timer cord and shielded viewing screen can also preclude chronic low level exposures to the x-ray unit operator.

(6) Long cone techniques are sometimes desirable but one can lose optimum density unless high kv is used. The long cone provides a decrease in intensity by inverse square effects, and enhances definition.

(7) Although the reproductive organs receive a small dose, lead aprons or equivalent gonadal or pelvic protective devices should be worn by the patient. In cases where it is necessary for the x-ray operator to be in close proximity to the patient, as when a child is being x-rayed, the operator also should wear an apron.

(8) If necessary, certain areas of the room should have lead-lined walls so as to eliminate stray radiation to adjacent areas. The lead thickness needs to be about 10–20 mils.

(9) A qualified expert should be consulted after these modifications have been made so that a good survey of the machine and general area can be made.

Summary

Dental roentgenograms are extremely valuable aids to the dentist. Their value must always be considered more important than the expense of a small local dose. However, where it is possible to reduce the exposure, with negligible diagnostic sacrifice, this must be done.

In our consultations with dentists who showed some concern in regards to the problem of x-ray hazards, we have seen some degree of satisfaction on their part when these simple and relatively inexpensive methods could be employed toward reassuring themselves and their patients.

Nevertheless, we strongly urge that corrective educational measures be provided. All accredited dental schools must have, as a required part of their curriculum, a course in radiation protection or equivalent. This training could later be imparted to the dental technician, if necessary.

In parallel with this act every manufacturer of x-ray machines must make it a point to provide all the aforementioned adaptations on their new equipment. If possible all their past customers should be informed of the potential hazards of their machines and recommended corrections initiated. In any event there should be an enthusiastic drive towards putting an end to the needless excessive exposure given to the unwary public.

Reference

1. Dobson, and Chupp: *Effect of Diagnostic Dental Radiography on the Lymphocyte Count and on the Diurnal Tide of Human Leukocytes.* UCRL-3574 (Oct. 1956).

The Envirec–An Instrument for Continuous Recordings of Environmental Air, Wet-Bulb, and Globe Temperatures, and Air Velocity

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IN A PREVIOUS publication[1] one of us (ADH) described a recording thermistor globe thermometer, which was developed for use in an environmmental heat study conducted in the summer of 1950. The purpose of this paper is to describe the development, construction, calibration, and use of an instrument for recording, on a single chart, the following four environmental factors: (1) ambient air temperature, (2) wet-bulb temperature, (3) globe (black ball) temperature, and (4) air velocity. These four factors are generally used for evaluating exposures to hot environments.[2] Since the authors were not aware of a single instrument for this purpose, work was begun in the winter of 1956 to develop one. A prototype was completed in the fall of 1957 and was field-tested in Florida in November of that year. The need for several modifications became apparent and the present model, shown in Figure 1, was completed in the spring of 1958.

Development of the Envirec

In the earlier model, thermistors were used as the sensing units for air and globe temperatures, and air velocity, while an El-tronics Humidity Senser was employed to measure relative humidity. A similar wafer was described by Wexler et al.[3] for determining relative humidities at upper altitudes during radiosonde balloon ascents. These investigators reported an accuracy of ±5% based on calibrating the logarithm of resistance against various relative humidities. We abandoned the use of this device after several frustrating months of experimentation because we never were able to achieve consistent and repetitive results. Another difficulty encountered with this humidity senser was its tendency to indicate lower humidities when exposed to radiant heat sources, and higher results at air velocities below about 50 linear feet per minute. As a last resort, the El-tronics senser was shielded with aluminum and a small blower was used to provide a constant flow of air over the senser. Even this modification did not result in consistent readings. Because of these difficulties and others, we resorted to an oral thermistor-thermometer probe, covered the end with a sling psychrometer wick, and connected the wick by means of rubber tubing to a small plastic bottle containing water. (See Figure 2.) This arrangement gave satisfactory and consistent results compared with a standard sling psychrometer. Thus, parts of our final instrument are somewhat similar to that described by Penman and Long.[4] In addition, we have incorporated a globe temperature sensing unit.

Operation

This instrument consists of four separate sensing or detecting circuits and a system for recording the output signal from each circuit successively and repetitively. The recording process utilizes a small cycling timer which drives a cam switch with five contacts. Output signals from air velocity, wet bulb temperature, globe temperature and air temperature circuits are selected by the cam switch. At the end of the 10-minute cycle the fifth contact provides a 10 millivolt signal, which is a full-scale deflection on the recorder, to give a distinct separation on the chart between the last recording (air temperature) and the beginning of another cycle (air velocity). A Leeds and Northrup portable Speedomax H strip chart recorder, 10 millivolt full-scale deflection, was available and used with this instrument. However, any standard servo recorder can be used with equally satisfactory results.

The air velocity sensing unit consists of a thermistor-bridge circuit in which the cooling effect of air circulating over a heated thermistor is used as an indicator of air velocity. Ambient air, globe and wet-bulb temperature sensing units consist of thermistor-bridge circuits. These four circuits are combined essentially as shown in Figure 3; they are mounted in and on an aluminum chassis, Figure 2; and are attached, by means of a 12-wire 20-foot extension cable, to the power supply and control panel contained in a separate chassis, Figure 1.

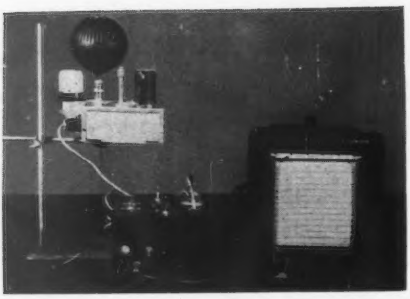

FIGURE 1. The Envirec—Sensing units, shown at upper left; power supply, at center; and recorder, at right.

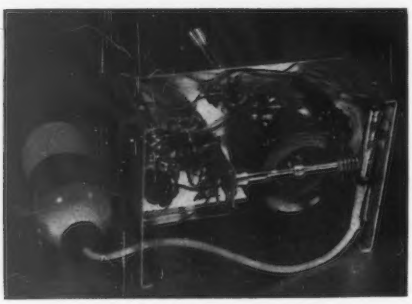

FIGURE 2. Interior view of chassis containing sensing units. Air and wet-bulb temperature probes are located near blower at right; air velocity tower is shown at upper center; and the copper float at left.

Construction Details

Air velocity: A finned tower, shown diagrammatically in Figure 4A and pictorially in Figure 2, was constructed from a one-inch diameter aluminum rod. It was polished to present a good reflecting surface to prevent absorption of radiant energy. The fins, machined from another piece of aluminum, were pressed into place on the tower. A hole, to clear a 2-watt carbon resistor, was drilled from the base to within about one-eighth inch from the top of the tower.

After an unsuccessful attempt to cement the thermistor bead in the side of the resistor with beeswax then to fill the void in the tower with the wax, the following procedure was used. The thermistor bead was dipped into epoxy resin just before the resin set up to completely insulate and protect the thermistor. It was inserted into a small hole drilled into the side of the resistor with slots to allow passage of the lead wires (see inset, Figure 4). All lead wires were covered with spaghetti tubing and this assembly was placed in the tower. As a final step, the cavity in the tower was filled with epoxy resin. After the resin hardened the tower was mounted on the aluminum chassis with three small machine screws.

Two thermistors are shown in the air velocity circuit; one is imbedded in the resistor (Figure 4A) and the other is physically located at about the middle of the ambient temperature tower, Figure 4B. The latter is used to compensate for ambient air temperature, the idea being that the bridge should remain in balance over a useful temperature range except for the cooling effect of air circulating around the heated thermistor. This temperature compensation is approximate only. If the ambient air temperature changes markedly, rezeroing in still air may be necessary. A one K-ohm potentiometer is provided for this purpose. In the earlier model, two ranges were provided; however, after calibration tests it was found that one range, from about 20 to 3000 linear feet per minute, was satisfactory for our purposes.

As indicated in Figure 3, the two thermistor beads form two legs of the Wheatstone bridge circuit. A 100-ohm resistor was selected for the third leg and a one K-ohm potentiometer made up the fourth leg of the bridge circuit. The potentiometer was adjusted to give a zero deflection on the recorder in still air after a 30-minute warm-up period. The calibrating resistor, indicated in Figure 3 with an asterisk beside the approximate value, was selected to give a full-scale recorder deflection at 3,000 fpm.

Air temperature: A similar finned tower was constructed except for a 7/16-inch diameter ball located two inches from the base as shown in Figure 4B and Figure 2. A hole, 5/32-inch in diameter, was drilled from the base to within 1/8 inch from the top of the tower. Lead wires of both thermistors were covered with spaghetti tubing and placed in position as indicated in Figure 4B. The cavity in the tower was filled with epoxy resin and, after hardening of the resin the tower was mounted on the chassis with three small machine screws.

The electronic circuit for this sensing unit is shown at the lower left of Figure 3. A double-pole, double-throw toggle switch, connected to various resistances, provides two temperature ranges. In the present model, however, only one range is used, from 75°F to 125°F. If another range is desired it can be provided by placing the proper resistances on the other side of the switch.

Wet-bulb temperature: This sensing unit consists of a Keystone L-0905-4875-112-S4 in an MRI oral probe, which is a small metal tube, four inches in length and about 1/4-inch in di-

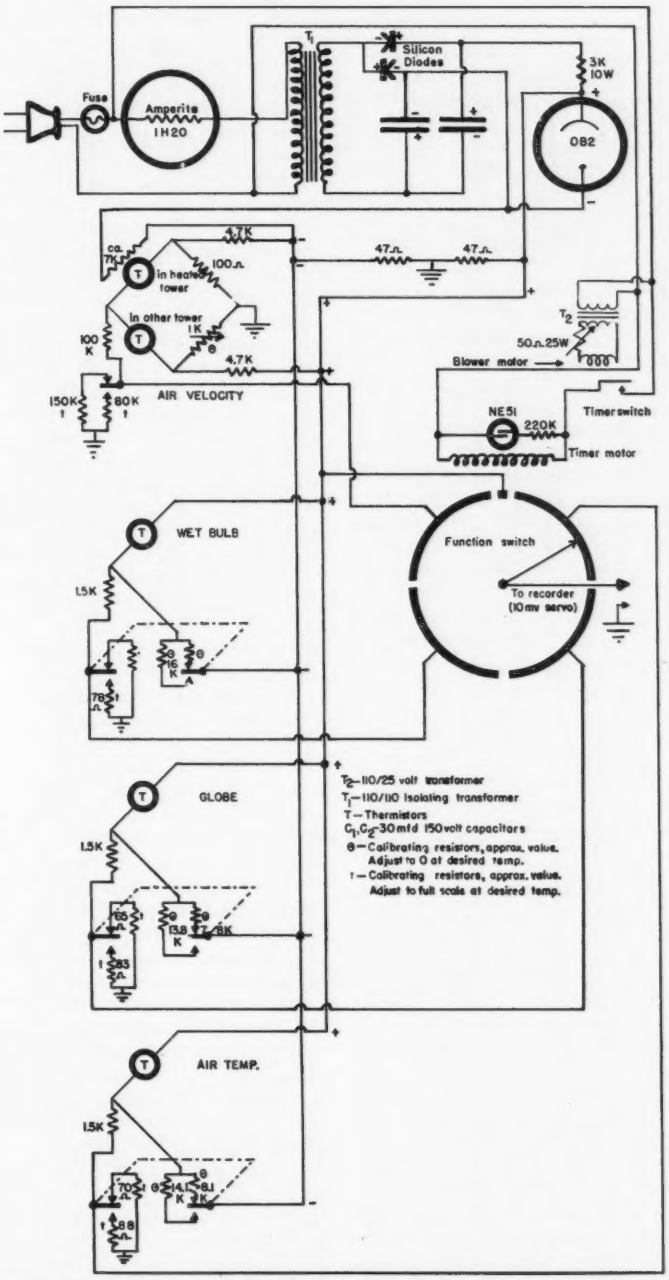

FIGURE 3. Schematic wiring diagram. The four sensing units are shown at the left.

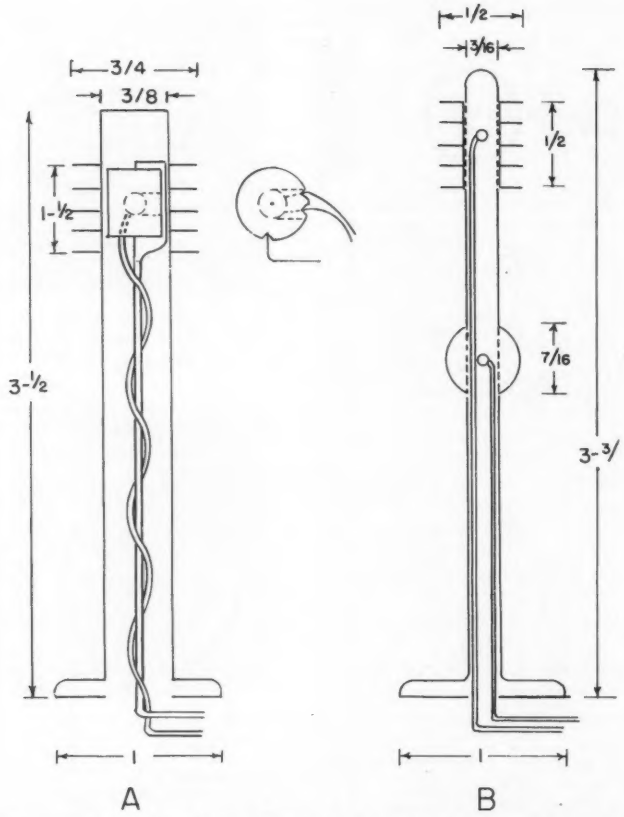

FIGURE 4. Construction details of air velocity detector, A, and air temperature detector, B.

ameter. The end of the probe containing the thermistor bead was covered with a 1-1/2-inch length of wick supplied with sling psychrometers. A small rubber band held one end in place while the other end was inserted into one end of a short length of surgical rubber tubing. The other end of the rubber tube was attached to the cap of a 250 ml plastic bottle mounted upside down as shown in Figures 1 and 2. A hypodermic needle was inserted at an angle into the bottle to prevent formation of a vacuum as water was withdrawn.

A small 27-volt war surplus blower (operated at reduced voltage it delivers about three cfm) was installed in an earlier modification to furnish continuous ambient air circulation around the El-tronics Humidity Senser and air temperature tower. This same blower, with a small slit cut in the chassis, permits a high velocity flow of air over the wet-bulb wick to ensure adequate evaporation of water.

The electronic circuit for this sensing unit is shown near the top at the left of Figure 3. Two ranges can be provided in a manner similar to the air temperature unit, but only one is used in the present model, from 50°F to 118°F.

Globe thermometer: This sensing unit consists of a 5-inch diameter, copper toilet float, coated inside and out with dull black enamel. A thermistor bead, also sprayed with black enamel, is mounted in the center of the globe and supported by the lead wires, encased in spaghetti tubing. An Amphenol, series 91 microphone connector, attached to the copper sphere serves to connect the sphere to the chassis and to provide electrical connections between the thermistor bead and bridge circuit. (See Figure 2.)

The electrical circuit, second from bottom, left, in Figure 3 is similar to the air temperature circuit except for the use of different resistance values. Two ranges can be provided by means of

the double-pole, double-throw switch with suitable resistors. Only one range is provided in the present instrument, from 75°F to 128°F.

General: Resistors shown in Figure 3 for the air, globe and wet-bulb temperature circuits were selected in the following manner. The thermistor beads in these sensing units are Keystone's L-0903-4875-112-S4 with a resistance value of 4875 ohms at 100°F. A potentiometer was inserted in the bridge circuit and the thermistors were brought to the lowest temperature desired. The potentiometer was adjusted until the recorder read zero, which is a balanced bridge condition. Resistance of the potentiometer was measured at this setting and it was replaced by an equal fixed resistor. This same procedure was followed for each of the three temperature units.

To obtain the upper temperature limits, the thermistors were brought to the desired temperature and a potentiometer was connected in place of the calibrating resistors indicated by asterisks beside their approximate values in Figure 3. The potentiometer was adjusted to give a full-scale recorder deflection and replaced with resistors of equal values. One or more temperature ranges may be provided in this manner. Two ranges are shown in Figure 3.

Continuous recordings from any one of the sensing units can be made by throwing a switch, which stops the electric timer during any portion of the cycle. This feature was particularly advantageous during calibration of the instrument and during subsequent field tests.

In the first model of this instrument, all sensing units were mounted on top of the power supply chassis. It was soon evident that some heat, enough to raise the temperature about 3°F in still air, was generated by the power supply, voltage regulator and other components. To overcome this difficulty, and to shield the air temperature tower and wet-bulb thermistor from radiant heat, we mounted the sensing units inside of and on a separate small aluminum chassis 6 by 9 by 11 inches. Electrical connections to the power supply chassis were made with a 12-wire extension cable. Thus, heat sources, other than those in the environment to be studied, were separated from the sensing units.

The size of the power supply chassis and physical arrangements of the electronic components is not critical. A chassis 6 by 9 by 5 inches high was found to be quite satisfactory. Four rubber feet were attached to the bottom plate and several small holes drilled in this plate to provide air circulation around the electronic components.

Calibration

Calibration curves for the air, globe, and wet-bulb temperature sensing units were prepared in the following manner. The entire chassis was placed in an electric oven using a Variac to control heat input. The small blower was operating and all electrical connections were made to the power supply and recorder. With the timer on wet bulb, the temperature of the oven was raised to about 65°F and maintained at any value near this by means of the Variac. When a constant temperature was reached the recorder reading was noted. This procedure was repeated at about 10°F intervals up to about 120°F. Current to the oven was turned off and several points were checked as the temperature decreased.

The same procedure was followed for the air and globe temperatures, checking one sensing unit at a time. Figure 5 is a plot of the data obtained in this manner.

In calibrating the air velocity sensing unit, it was necessary first to zero the unit. This was accomplished by moving the apparatus into a small inside dark room where the air velocity was 15 linear feet per minute (fpm) or less with the ventilation system turned off. After a 30-minute warm-up, the resistor potentiometer was adjusted to give a zero scale reading on the recorder. We decided to use 0.6 millivolt as the zero setting because this allowed us to determine if the zero setting would drift upward or downward. Several checks were made throughout one day with the instrument in continuous operation. Repeat zero checks were made on a number of different days and it was not found necessary to readjust the potentiometer. It was discovered later that a satisfactory zero check could be made by placing a plastic bag over the top portion of the chassis.

In order to cover a wide range of air velocities, from about 50 to 3,000 fpm, we utilized a ventilation system set up in our laboratory for training purposes. By varying the blower motor speed and the number and size of duct openings, it was possible to achieve this range of air velocities. A heated thermoanemometer probe (previously calibrated against a Pitot tube) was placed within one inch and parallel to the air velocity sensing unit. The entire chassis was then positioned at the center of a 14-inch square duct opening. After several experimental runs we were able to maintain quite constant air flows at a given velocity. It was found that the air velocity sensing unit came to equilibrium in about three to five minutes at air flow increments of about 100 fpm. About 10 minutes was required to reach equilibrium from still air to 3,000 fpm and an equal time

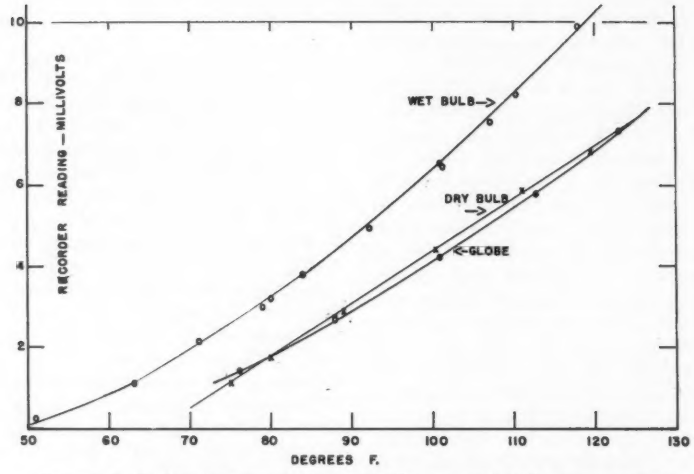

FIGURE 5. Calibration curves for wet-bulb, air, and globe temperatures.

for the recorder to return to its zero setting after the blower was turned off. Figure 6 is the calibration curve obtained from these data. It will be observed that a recorder reading of 2 represents 35–40 fpm. The graph indicates a slight S-curve since 0.6 was arbitrarily chosen as the zero setting; however, at an air velocity of 22 fpm the recorder read 0.7. For this reason the curve was extended as a straight line in the manner shown. It was most difficult to maintain constant air flows below about 50 fpm during several attempts while calibrating the instrument. Since we are generally interested in determining if the general air movement in a plant is 50 fpm or lower or above 50 fpm in increments of 50 fpm, we believe this instrument is sufficiently accurate for this purpose.

After the instrument was calibrated in the manner described above, the calibration curves were checked while the instrument was operated under various laboratory conditions of temperature, humidity, radiant heat and air flows. Radiant heat could be increased or decreased, air temperatures and humidities could be varied by means of three, 10-ton air conditioners, and air velocities from about 75 to 3000 fpm could be obtained by placing the instrument at different distances from the discharge of a large blower. A standard sling psychrometer, heated thermoanemometer, and thermometer placed in the globe's center, was used for this purpose. Temperature readings were well within ±1°F of the calibration curve; however, we hesitate to claim better than 99% accuracy at low air velocities (below about 100 fpm) or 95% accuracy at the higher air flows.

Performance

Figure 7 illustrates reproducibility of results using the instrument. This section of the chart, from about 5:20 a.m. to 7:40 a.m. on July 30, 1958, was the result of an overnight test of the instrument in our large basement laboratory. Since the laboratory is vacant from about 4:30 p.m. until 8:00 a.m. the following morning, and since all lights as well as the ventilating system were off during that time, ambient air conditions became stable before midnight and remained relatively constant. This section of the chart indicates an air velocity of practically zero, certainly no greater than 15 fpm; wet-bulb temperature of 70°F; globe temperature of 82°F; and air temperature of 83°F. Thus, the relative humidity was 55%. Sling psychrometer readings at about 8:15 a.m. that morning were: DB = 82.5°F, WB = 69.5°F, or about 53% relative humidity.

Through the cooperation of the Kentucky Division of Occupational Health the instrument was used in preliminary investigations of environmental heat exposures at two plants during the month of August 1958.

Workers in one large area of the first plant studied were exposed to high radiant heat sources during the process of enameling bathtubs and other sanitary fixtures. In the particular area under study, a three-man team placed a bathtub to be enameled into one of two gas-fired furnaces maintained at about 1750°C. When the tub was heated to the required temperature (cherry red) it was withdrawn from the furnace and placed on a jig. Enamel powder was dusted onto the inside,

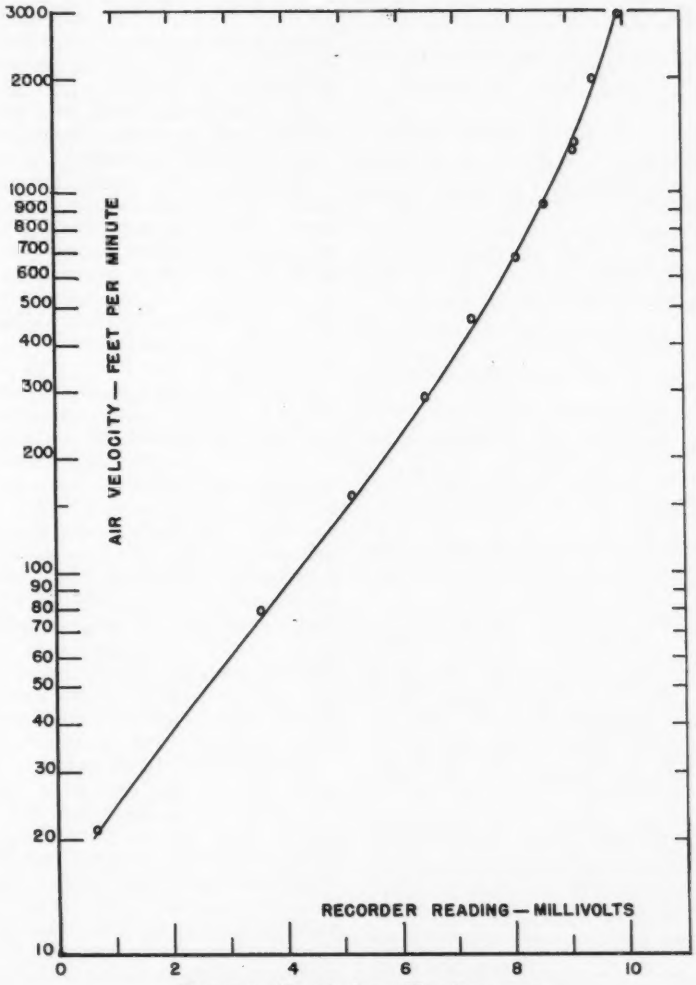

FIGURE 6. Air velocity calibration curve.

edges, and front portion of the tub. It was returned to the furnace where the powder fused to form a glass-like enamel finish. Ordinarily, two applications of the enamel powder are required with frequent inspections and touch-ups before the tub is finished. Thus, the tub is placed into and removed from the furnace several times and each time the workers are exposed to radiant heat from the tub as well as from the open furnaces. About 24 tubs are completed by one team in a six-hour shift.

This company had experimented with several methods to control radiant heat exposures and to reduce the effective temperatures. The controls in use at this time were: (1) aluminum shields on the inside of all furnace doors, (2) aluminum shields between the furnace and the chief enameler's work station, (3) an aluminum shield suspended from a trolley, which could be placed between the hot tub and chief enameler, (4) a small aluminum shield placed at floor level between the tub and foot-operated controls for the jig, (5) protective clothing for the chief enameler consisting of an aluminum face- and head-shield and an aluminized cloth apron and arm sleeves, and (6) a source of filtered and washed fresh air, discharged about 4 feet from the chief enameler through a rectangular, adjustable louvered opening.

Figure 8 is a portion of the recorder chart from

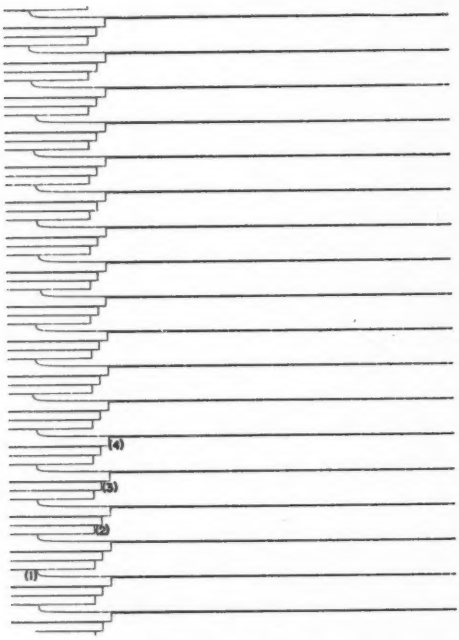

FIGURE 7. Section of chart from 5:20 a.m. to 7:40 a.m. on 7/30/58 showing consistent results following an overnight run in laboratory. Air velocity, (1), is essentially zero; wet-bulb temperature, (2), is 70°F; globe temperature, (3), is 82°F; and air temperature, (4), is 83°F.

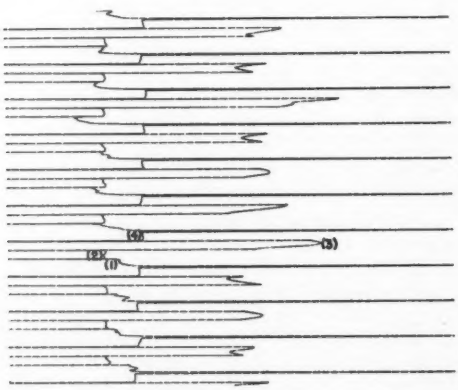

FIGURE 8. Portion of chart from 11:15 a.m. to 12:45 p.m. 8/20/58 with instrument located about six feet from worker enameling bathtubs. Air velocity, (1), about 45 fpm; wet-bulb, (2), 72°F; globe temperature, (3), varied from 107°F to 125°F; and air temperature, (4), 89°F to 91°F.

11:15 a.m. to 12:45 p.m. with the sensing units located about six feet from the chief enameler's work station. This section of the chart illustrates the fluctuations in radiant heat and fairly constant air conditions while four bathtubs were enameled. At this location, the globe temperature varied from 107°F to 125°F, air and wet-bulb temperature and air velocity was fairly constant at 89°F to 91°F, 72°F and 45 fpm respectively. Fresh air was discharged from the source near the operator at about 300 fpm (estimated) with dry-bulb and wet-bulb temperatures of 77°F and 72°F, with a corresponding 80% relative humidity. At 10:40 a.m. outdoor temperatures were 82.5°F DB and 69.5°F WB representing 53% relative humidity.

In the afternoon, the globe thermometer was suspended directly over and about two feet above the chief enameler's head. An extension cable, covered with aluminum foil, connected the globe to the sensing unit chassis. Figure 9 shows a portion of the chart between 2:10 p.m. and 2:55 p.m. Note that the globe temperature reading was off scale most of this time (estimated at over 140°F), while the chief enameler was applying powder or inspecting the tub. During a portion of this 45-minute period both furnace doors were open. The decreased globe temperature, shown by the on-scale readings, occurred when the tub was replaced in the furnace and the furnace doors closed. This still represents an exposure of about 125°F.

In order to calculate the effective temperature at the chief enameler's station, it would be necessary to suspend the small aluminum chassis containing all the sensing units, above and beside him. We were not prepared for the situation which was encountered. It was impossible, because of the nature of this operation, for us to move the equipment closer than six feet from the operator. At this distance, however, the chief enameler would have been exposed to a maximum effective temperature of 93°F corrected for radiant heat. His actual exposure would probably be greater than this in spite of the control measures in use.

While the chief enameler and his two helpers are not engaged in operations near the furnace, they perform various tasks in an area about 35 feet from the furnaces but directly in front of them. The instrument was moved to this location and allowed to record for about 45 minutes. At this time, outdoor conditions were 90.5°F dry bulb and 72°F wet bulb. Figure 10, a portion of the recorder chart during this time, shows the dry-bulb and wet-bulb temperatures are 92°F and 72°F. Globe temperatures varied from 98°F to 102°F and air velocity averaged less than 70

fpm. Thus, while the workers were supposedly recovering from high radiant heat exposure during these rest periods, they were in effect still exposed to effective temperatures (corrected to include radiant heat) of about 85°F. Most industrial hygienists would recommend control measures for reducing exposures to effective temperatures of this magnitude.

The instrument was returned to its original location, that is, six feet from the chief enameler. It was operated continuously in that location from 4 p.m. until 8:40 the next morning without any mechanical difficulties in spite of the high radiant heat. Environmental conditions were essentially the same during the next two shifts.

A brief run with the instrument was made in the carding and spinning rooms of a cordage plant on August 21, 1958. Unfortunately (for us at least), the outdoor temperature was quite pleasant that day (DB = 84°F to 86°F, WB = 70.5°F to 72°F), with resulting indoor temperatures varying from 85°F to 88°F dry bulb and 74.5°F to 76°F wet bulb. Air velocity averaged 60 fpm and lower and there were no sources of radiant heat. On this basis, effective temperatures varied from 79°F to 81°F, which in the absence of radiant heat does not pose a heat problem.

No attempt will be made in this paper to interpret the results of these limited studies. They were described briefly in an effort to demonstrate the type of industries in which our instrument was field-tested and to show samples of the data obtained.

Discussion

There has been a long standing need for an instrument of this nature and the authors believe that the one described, or modifications of it, will satisfy the requirements for a portable, dependable, recording instrument for environmental heat studies. The authors do not claim originality in this project, except for utilizating principles demonstrated by other investigators to be practicable and combining these into a single unit.

No mention has been made of cost. Outside of developmental costs which are primarily time, the electronic components, except for the recorder, were obtained at a local electronics supply house for about $100. Price of the recorder was about $1500 two years ago but it is used for other laboratory purposes as well.

Limited field tests to date indicated the necessity for at least two changes and the desirability of other modifications. It became apparent in the first plant that the globe temperature range should be extended. Two ranges, 60°F to about 120°F and 115°F to about 160°F, should cover

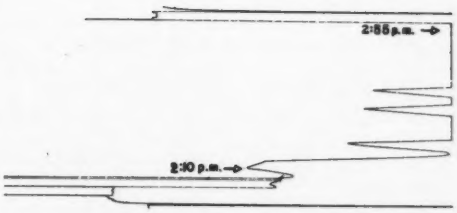

FIGURE 9. Section of chart from 2:10 p.m. to 2:55 p.m. on 8/20/58 recording globe temperature only with sensing unit suspended above chief enameler's head. Note rapid rise in globe temperature to nearly an off-scale reading when instrument turned on at 2:10 p.m. Also note that recorder was off-scale for most of this 45-minute period.

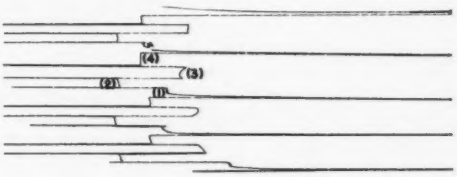

FIGURE 10. Instrument was moved 35 feet from furnaces at 3:20 p.m. Air velocity, (1), varied from about 65 to 140 fpm; wet-bulb, (2), 72°F; globe temperature, (3), 98°F to 102°F; and air temperature, (4), 92°F.

nearly all situations. This can be accomplished rather simply except for the chore of recalibration. Even though the power supply and recorder were located about 20 feet from the furnaces and 10 feet from the cherry red bathtub in the first plant, both pieces of equipment became quite hot. Constructing the power supply chassis from unpainted aluminum and covering four sides of the recorder with sheets of aluminum should overcome this difficulty.

Among the desirable modifications, some means should be devised to suspend the entire sensing or detecting unit as near as possible to the worker. A heat-resistant, 12-wire cable would then be needed to connect the unit to the power supply. The ideal detecting unit should be able to telemeter information on the workers' exposure to hot environments to a central recorder. Several detecting units could be located in an area, or attached to workers, and the information from these could be relayed to a multichannel recorder.

Conclusion

A single instrument for recording on one chart environmental conditions of air velocity, air, globe, and wet-bulb temperatures was developed

and described. The sensing units consist of thermistors with appropriate bridge circuits.

It is believed that this instrument or suitable modifications will prove to be a useful tool for those industrial hygienists who have occasion to conduct heat studies in industry or in other environments. A limited number of field tests demonstrated that the instrument could be operated for at least 24 hours in areas where high globe temperatures (over 140°F) were encountered; that the data were obtained with minimum effort on the part of the survey team; that the results obtained appeared to be consistent with visual and sensual observations and checks with conventional instruments; and, finally, these tests proved the practicability of this instrument compared with conventional instruments used for this purpose.

Acknowledgments

The authors gratefully acknowledge the assistance of their colleagues during the course of this project and in reviewing this manuscript. Particular thanks are due to Mr. Howard L. Kusnetz for the drawings; to Messrs. David A. Fraser and Marshall LaNier for the photographs; to Mr. Howard E. Ayer for his assistance in calibrating the air velocity detector; and to Mr. Oscar Marsh who fabricated many of the component parts of the instrument. The generous assistance of Mr. E. Norman Schell, Director, and James Scudder, Engineer, Kentucky Division of Occupational Health, in arranging for and participating in field testing of the instrument, is also sincerely appreciated.

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Industrial Water Conservation

A SHORT COURSE ON Industrial Water Conservation has been scheduled for June 8 and 9, 1959 at the School of Public Health, University of Michigan, Ann Arbor, Michigan. This course has been developed on request of several groups as a short, intensive course to explore what is being done by industry to cut down on its use of water. The course is directed to industrial people at the plant engineering and upper management levels. For detailed information write to H. E. Miller, Director, Continued Education, School of Public Health, University of Michigan, Ann Arbor, Michigan.

Analysis of Blood for Boron

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THE analysis of blood for boron, like that of tissue, requires destruction of the organic matter prior to the application of known methods of boron analysis, such as the carmine method of Hatcher and Wilcox,[1] or the turmeric method of Naftel.[2] Existing procedures were discussed and a new alkaline digestion method was offered in a paper by Hill *et al.*,[3] but even the latter still had some shortcomings, largely tediousness, which it was desired to overcome. A fast method for tissue destruction by combustion in an oxygen atmosphere was published in a recent issue of this journal,[4] and its possible applicability to blood was indicated. Work on this problem has now been completed, and a brief summary of the results obtained are given herewith.

The same type of Parr Oxygen Bomb and the same general methodology as was employed for tissue combustion is also used for the destruction of blood, and only the briefest references to the apparatus and the process will, therefore, be made here.

The blood used for analysis should contain an anti-coagulant (oxalate, heparine, etc.) for obvious reasons. A pellet is formed by compressing about 0.8 grams of S & S Ash Free Analytical Filter Pulp to approximately 1.75 centimeter in the Parr pellet press. Up to 2.0 ml of blood, accurately measured, is pipetted directly onto the pellet, leaving top and bottom free of blood. The paper pulp absorbs the blood rapidly and the entire operation is very clean and the time required is minimal. The pellet containing the blood sample is placed in the combustion capsule and the fuse wire is made to contact the top dry portion of the pellet. The head assembly, which holds the combustion capsule, is placed in the Parr Bomb and the apparatus is sealed by means of the screw cap. The air in the bomb is displaced by pressuring with five atmospheres of oxygen and bleeding off. Then the bomb is pressured with 25 atmospheres of oxygen, the oxygen supply is disconnected and the valve thumb nut is replaced. After setting the bomb in the cooling tank and connecting a power source, the sample is electrically ignited by pressing the firing button.

After a 10-minute cooling period, the bomb is removed from the cooling tank and the internal pressure is allowed to reduce to atmospheric pressure by opening the valve slightly. The bomb is then opened, the capsule and bomb washed out thoroughly into a volumetric flask of appropriate size and the sample is diluted to volume with distilled water. Aliquots of this solution are analyzed for boron, without further treatment, by any one of the well known methods, such as the carmine method of Hatcher and Wilcox.[1]

In order for analyses of biological materials to be meaningful, it is often necessary to determine the "normal" content of the element or compound to serve as baseline value for comparison with samples of abnormal or elevated content. This frequently involves handling large quantities of sample because of the very low content of the component sought and the limited sensitivity of the analytical procedure used. An alternative method is to incorporate the normal material being analyzed into the procedure as a blank. The difference between the blank and the unknown represents the absolute elevation of the component sought in the material analyzed. As a compromise in cases where the "normal" content is known to be insignificant with respect to elevated content, it may be ignored and the unknown determined against a reagent blank.

It has become known through other investigations[3] that "normal" human and animal blood contains only a very small quantity of boron, in the order of magnitude of one to several tenths of one per cent. This quantity is so small that combustion of two ml of blood by the Parr Bomb method does not yield enough boric acid to be determinable with accuracy by the carmine method customarily employed in this laboratory, though the turmeric method with its much greater sensitivity should be applicable. Nevertheless, samples of normal human blood were burned in the Parr Bomb and the results obtained are of the right order as is seen from Table I. These figures make no claim to great accuracy because of instrumental limitations in the range of transmittancies encountered. However, the high light transmittancies observed are

* In partial fulfillment of the requirements for the degree of Master of Science in Hygiene, University of Pittsburgh, 1958. Present address Tennessee Valley Authority, Wilson Dam, Alabama.

TABLE I

Boron Content of Human Control Blood, by Parr Bomb Destruction and Carmine Analysis

Sample		% Transmittance after 45 minutes	Boron content, micrograms per ml
Number	Size (ml)		
1	2.0	96.6	0.1
2	2.0	96.6	0.1
3	2.0	88.1	0.4
4	2.0	91.0	0.3

TABLE II

Analysis of Human Blood Containing Added Boric Acid, by Parr Bomb Destruction and Carmine Method

(2.0 ml samples)

Boron added, micrograms/ml (Theoretical)	Analytical results	
	Boron content* micrograms/ml	Boron content** micrograms/ml
1.0	1.2	0.7
2.0	2.0	1.6
3.0	3.0	2.4
4.0	4.1	3.6
5.0	4.7	4.2

* Spectrophotometric readings against chemical blank
** Same samples read against blood blank

TABLE III

Analysis of Human Blood Containing Added Boric Acid, by Parr Bomb Destruction and Alkaline Digestion—Methyl Borate Distillation

(2.0 ml samples)

Boron added, micrograms/ml (Theoretical)	Parr bomb method		Alkaline digestion and methyl borate distillation					
			Test 1			Test 2		
	Test 1	Test 2	Distillate	Residue	Total	Distillate	Residue	Total
3.0	2.6	2.7	3.0	0.0	3.0	2.6	0.7	3.3
5.0	4.0	4.2	3.7	0.5	4.2	3.3	0.5	3.8

indicative of complete combustion of the organic material present in the blood because organic material in samples always causes darkening of the sulfuric acid in the carmine test with resulting low transmittance values.

The same normal human blood was spiked with boric acid and then subjected to Parr Bomb combustion and carmine analysis for boron. Table II shows that recoveries were quite satisfactory. A comparison of analyses obtained on such spiked blood by the well proven alkaline digestion method and the Parr Bomb method showed that both procedures give similar results. They are reported in Table III.

TABLE IV

Analysis of Exposed Rabbit Blood Comparing Parr Bomb Destruction and Alkaline Digestion —Methyl Borate Distillation

Exposure: I.V. injection of dimethylamine-borane

Blood sample	Determination number	Boron content, Micrograms per ml			
		Bomb destruction		Digestion-distillation	
A	1	13.0		11.7	
A	2	12.6	12.8	12.3	12.2
A	3	12.8*		12.6	
B	1	12.6		9.9	
B	2	12.2	12.5	12.0	11.2
B	3	12.8*		11.8	
C	1	12.2		12.3	
C	2	12.2	12.1	12.3	12.1
C	3	12.0*		11.7	

* Represents 2 ml blood samples—all others were 1 ml. Sample A was drawn from the animal first, then sample B, and last sample C.

In order to try out the method on blood samples as they might be obtained in the toxicological investigations carried out in this laboratory, a solution of dimethylamine borane was given intravenously to a rabbit. After allowing a few minutes for equilibration, blood samples were taken for boron analysis. Because the blood samples were taken sequentially, it was speculated that there might be differences in the boron content of the three samples. Therefore, they were designated as samples A, B, and C and were analyzed for boron by the carmine procedure, employing both the Parr Bomb and the alkaline digestion method for destruction of the organic matter of the blood. It is evident from Table IV that the two methods of blood analysis give very comparable results but with better precision for the Parr Bomb method.

It is suggested that for very low boron levels, as are encountered with control blood samples, several aliquots be burned successively in the Parr Bomb and brought to analysis together. The likelihood is considered good that the method will lend itself to the analysis of blood for elements other than boron.

Summary

It has been shown that the Parr Oxygen Bomb can be used for the speedy destruction of blood

preparatory to boron analysis by known procedure and that precision of the method is better than that of the alkaline digestion procedure.

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Industrial Solvents

A *HANDBOOK OF ORGANIC INDUSTRIAL SOLVENTS* designed to provide safety engineers with fundamental information on recognition and evaluation of solvent problems and on the principal methods of control has been published recently by the National Association of Mutual Casualty Companies. This 72-page booklet was prepared by the Association's industrial hygiene committee and brings together material not previously available in a single publication. Largely a compilation of existing data, it covers the physical, chemical, and toxicologic properties of the common industrial solvents.

New material on solvent evaporation rates was developed by Dr. L. D. Wilson as a research project for the Association. Comments on the physiologic and toxicologic effects of the solvents are by Warren A. Cook. In the absence of specific information on toxicity of cetain solvents, the handbook gives probable effects on the basis of the action of similar compounds; when such analogies are used, it is indicated clearly.

Single copies may be obtained without charge from F. H. Deeg, National Association of Mutual Casualty Companies, 20 North Wacker Drive, Chicago 6, Illinois.

Field Method for the Determination of Inorganic Lead Fumes in Air*

ENRIQUE A. QUINO

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LEAD fumes in concentrations above 0.2 mg Pb per cubic meter of air may constitute a health hazard if inhaled daily for an eight hour period. It is important to the industrial hygienist to have a field method for quantitative estimation of small amounts of lead in the air.

The purpose of the present investigation has been to develop a suitable field method for the determination of lead fumes in air in order to provide an accurate and immediate evaluation of possible lead hazards in the working environment. Kits for lead-in-air determinations are marketed at present. Our experience, however, has indicated that while these kits detect the presence of relatively large amounts of lead, they do not provide satisfactory quantitative information in the lower concentration ranges of interest to industrial hygienists. The field method described in this paper may not have accuracy to the microgram as does the chemical method using dithizone, but it does provide satisfactory quantitative information in a very short time and at minimum expense. Furthermore, the results obtained with this field method compare favorably with those by the chemical method, as shown later.

A review of the literature reveals that accurate analytical methods are available but that they are time consuming and not easily adapted to field use. A spot test for lead has been known for some time.[1]

Two possible field test methods have been reported: (a) The method of L. Silverman and M. Amdur[2] which involves the reaction of lead with tetrahydroxyquinone in an acid medium to give a color-complex stain on filter paper. We have found that the 0.2% alcoholic solution of tetrahydroxyquinone does not retain its activity for longer than a day. Sometimes with freshly prepared solutions we were unsuccessful in obtaining a colored complex even with concentrations of lead in air greater than 0.2 mg Pb per cubic meter of air. (b) A method[3] wherein a stain is developed by adding to lead collected on filter paper a drop of ethanol solution containing a suspension of sodium tetrahydroxyquinone and buffer solution. We found that this method did not produce uniform colorations on the filter paper; also, comparisons of concentrations of lead in air determined by use of the color standards with chemical analyses by the dithizone method showed significant discrepancies.

It is known that tetrahydroxyquinone solution has an affinity to form a pink lead complex even with so-called insoluble materials as lead sulfide.[1, 5] Our tests have confirmed the fact that lead arsenate, lead carbonate, lead nitrate, lead chlorate, lead chromate, etc., form a pink complex with tetrahydroxyquinone. Since the intensity of the stain has been found to be proportional to the concentration of lead, the concentration of lead compounds in air can also be determined.

A somewhat different approach to the abovementioned techniques has been taken. Instead of using ethanol containing tetrahydroxyquinone in suspension, an acetone-water solution of tetrahydroxyquinone was used. Different organic solvents were investigated in order to prepare a solution of tetrahydroxyquinone which could provide a stable color complex and sensitive reaction with lead. It was found that a mixture of acetone and water completely dissolved the tetrahydroxyquinone giving a clear orange colored solution. The intensity of the lead complex stain formed when using the aqueous-acetone solution and Whatman paper No. 42 was considerably greater than that produced by existing techniques using identical concentrations of lead. The stains formed are also made uniform, i.e. the difficulty of ring effect has been virtually overcome.

Air samples were collected close to a source of lead fumes, through a high collection efficiency filter paper[4] retained in a filter holder and attached to a Uni-Jet sampler as shown in Figure 1. After sampling, color stains were developed on the filter paper and matched with prepared color standards. For control determinations, all filter papers containing the pink stain were subsequently analyzed for lead content by the dithizone method.

* Prepared for presentation at the 1959 annual meeting of the American Industrial Hygiene Association in Chicago, Illinois.

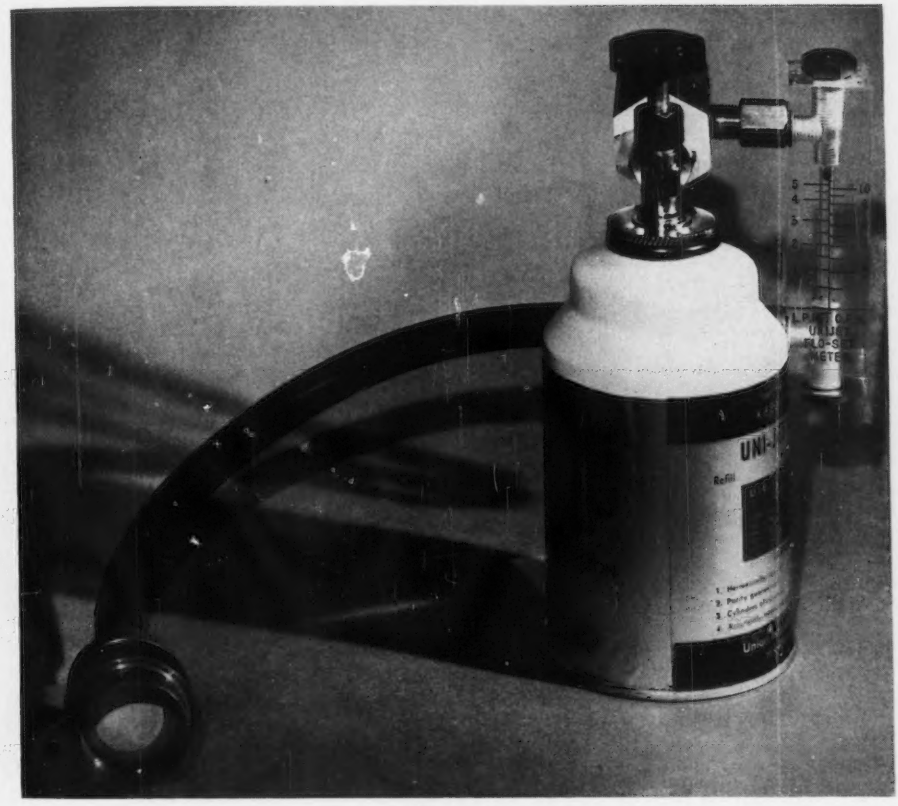

FIGURE 1

Reagents

Tetrahydroxyquinone Solution: Dissolve 0.3 gm of disodium tetrahydroxyquinone in 0.5 cc. of distilled water, and add slowly 1 cc of acetone. A clear orange colored solution should be obtained. This solution should be prepared just prior to use in the field. It should be stored in a small glass bottle provided with a dropper made to deliver 0.02 cc per drop. Optimum results were obtained with freshly made solutions. Solutions kept in all glass containers are stable for more than 24 hours. The salt and the solutions kept separately in glass containers can be stored for long periods of time (years). The disodium tetrahydroxyquinone used was Fisher THQ Catalog No. T-116.

Buffer Solution, pH 2.8: Dissolve 0.0998 mole of sodium bitartrate plus 0.0998 mole of tartaric acid in 100 cc of distilled water. This solution can be stored for long periods of time in plastic as well as glass dropping bottles.

Apparatus

Filter holders containing No. 42 Whatman paper were used in our studies. The filter paper and filter holder assembly should be tested for leakage.

Filter Paper, 2.5 cm. diameter Whatman No. 42. 2.0 cm was the effective diameter of the filter.

Uni-Jet Air Sampler U.I.E.-175 calibrated from 0–5 lpm, obtained from Union Industrial Equipment Corporation.

Color Standards

A series of atmospheric samples was taken close to a source of lead fumes at different intervals of time. Coloration was developed on the filter paper by adding to the collection surface of the filter two drops of tetrahydroxyquinone solution, followed by two drops of buffer solution. Gradations of color were obtained and grouped according to the color in-

TABLE I

Comparison of Field Method and Chemical Analytical Method (Dithizone) in Estimating Lead Concentrations

(Results in mg Pb/cubic meter of air.)

Sample No.	Visual Method	Chemical Method
1	0.10	0.090
2	0.15	0.160
3	0.20	0.210
4	0.25	0.235
5	0.30	0.300
6	0.35	0.340
7	0.40	0.450

tensity of the stain. Six filters showing the same stain intensity were assigned to a single group. To find the exact amount of lead corresponding to different stain intensities, five filters were taken from each group for chemical analysis and the remaining one used as the color standard. Chemical analysis of the filters by the dithizone method indicated that stain intensities were proportional to the amount of lead on the filter paper. Lead concentrations in air corresponding to different stain intensities were calculated from the amount of air sampled and the concentration of lead found in the stain by the dithizone method.

Four color standards were chosen corresponding to 0.100, 0.200, 0.300, and 0.400 mg Pb per cubic meter of air. For convenience in making estimations of lead concentrations, the four color standards were arranged in a radial pattern on a circular disk which was provided with a central aperture. Unknown samples were placed in the aperture for direct visual comparison. Color standards have been found to be stable for six months or more without change in color intensity. If a field comparator is to be constructed, artificial colors may be used to reproduce the stain color and intensity.

The ordinary procedure for making color standards by means of preparing solutions of soluble lead compounds was not used because the stains thus obtained did not exhibit the typical speckled pink stain obtained when lead fumes are collected on filter paper.

Sampling Procedure and Analysis

Air samples were taken for ten minutes, at the rate of 4–5 liters per minute, through Whatman No. 42 filter paper placed in a filter holder and connected to the Uni-Jet sampling apparatus as shown in Figure 1. If such apparatus is not available, air samples can, of course, be obtained by other suitable sampling apparatus. After sampling, the filter is removed from the filter holder and two drops of tetrahydroxyquinone solution are added to the center of the filter. After approximately 20 seconds, two drops of buffer are added. The stain obtained is then compared with the color standards. Concentrations of lead in air which have intermediate values between the 0.1, 0.2, 0.3, and 0.4 mg standards can be estimated by interpolation. Our results indicate that the error of the visual estimations of lead concentration in air will not be greater than 0.05 mg Pb per cubic meter of air from the chemically determined value. When the stain intensity is greater than that given by the highest standard value (0.4 mg Pb per cubic meter of air), it is difficult to visually estimate the concentration.

Blank determinations on several hundred Whatman 42 filters were sufficiently low to guarantee consistent results. Ordinary care in the field use of these filters, such as handling with clean hands or tweezers and storage of filters in a suitable box or container, should yield satisfactory blanks. Perhaps a blank determination should be made with each series of samples to give reassurance of no contamination.

Table I shows some representative results obtained by the visual method and by chemical analysis using the dithizone method.

Interference by Other Metals

No interference was detected from Zn, Sb, As, Cr, Ca, Bi, Cu, and Fe in equal proportions to the lead. When concentrations of cadmium are double the lead concentrations, a slight interference is observed, but is not significant.

Comments

The field method described should be especially useful to the industrial hygienist for environmental surveys away from laboratory facilities since it provides immediate and accurate determinations of lead concentration in air. The method also makes the shipment and storage of bulky atmospheric samples unnecessary. The saving in analysis time is illustrated by the fact that analysis of 24 atmospheric samples by chemical methods usually takes eight hours or more; the field method for the same number requires ten minutes or less.

The stains obtained on the filter paper have remained stable thus far for a period of seven months. Immediate comparison of color intensities in the field is therefore unnecessary. This is of practical importance where time may not permit direct reading of stain patterns.

All filter paper samples can still be analyzed by chemical methods, if desired, even after estimation of lead concentration by the lead complex coloration. The Whatman No. 42 filter paper can be dissolved easily for the analysis by heating in a beaker containing 0.2 cc of H_2SO_4 and 1 cc of HNO_3. The equipment used for sampling weighs approximately 2.5 pounds, is easy to operate, can be used with safety in "hot" areas where volatile explosive vapors may exist, and is low priced.

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Emergency Exposures to Radiation

THE NATIONAL COMMITTEE on Radiation Protection and Measurements, Subcommittee 14—Permissible Exposure Dose under Emergency Conditions has been working for several years in an endeavor to develop an adequate picture of the effect of large doses of radiation that may be received by large groups of people under emergency or disaster conditions (such as nuclear warfare or the disruption of a large reactor). Doses being considered by this subcommittee are not being regarded as permissible. The forthcoming report, however, is intended to outline the effects to be expected from large exposures. In the event of nuclear warfare the prime consideration of the population will be immediate survival and therefore large doses may have to be accepted without regard to long-range effects. It is hoped that the handbook when completed will provide some guidance for the policy decisions that will have to be made under emergency conditions.

The program of this committee was started under the acting chairmanship of L. S. Taylor. The permanent chairman is now Dr. George Leroy, Billings Hospital, University of Chicago, Chicago, Illinois.

Evaluation of Methods for the Determination of Halogenated Hydrocarbons in Air*

E. E. CAMPBELL, M. F. MILLIGAN, and H. M. MILLER

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THE purpose of this study has been to make a comparative evaluation of methods of air sampling and analysis for chlorinated hydrocarbons in general, and for trichloroethylene in particular. Four analytical methods were used: a modified Fujiwara, the mercuric thiocyanate colorimetric, the mercuric nitrate, and the silver nitrate titrimetric. We have excluded from consideration instrumental methods of analysis and those which require complicated furnace units suitable for use only in a laboratory.

Analytical Methods

The Fujiwara method has been criticized because of its lack of specificity and reproducibility. The introduction of various modifications has led to some confusion and dissatisfaction with the method. The modification described by Seto and Schultze[1] seems the best developed to date, and we have used it for the analysis of trichloroethylene. The only modification we have applied to the described technique is a more rigorous control of the reaction times during the addition of the reagents and final reading of the diluted color. The following outline and time schedule are used:

Prepare standard solutions of trichloroethylene in toluene with a range of 5 to 30 μg of trichloroethylene per milliliter. Dilute the air sample in toluene to 100 ml volume. Place one milliliter of each standard and unknown in a 19 × 105 mm round Coleman tube. To each tube, add 5 ml of redistilled pyridine. Use a timing chart and a stop watch for the remainder of the procedure. Add 0.35 ml of 1% potassium hydroxide in ethyl alcohol and mix. Exactly five minutes later, add one ml of distilled water and mix. Exactly six minutes later, add 3 ml of 95 per cent ethyl alcohol, mix, transfer to a reference Coleman tube, and read the per cent transmission at 545 millimicrons. The concentration of the air sample is determined from a plot of the standard curve.

The interferences of 12 chlorinated hydrocarbons were studied and only s-tetrachloroethane interfered at the same concentration as the trichloroethylene. The standard curve is linear within the range described and each point reproducible within a given set of analyses, although it is not always reproducible with previous standard curves.

The other procedures involved the dehalogenation of the chlorohydrocarbon molecule, so that the chloride ion could be determined. These procedures require more meticulous laboratory housekeeping than is usual, and particular care must be exercised in cleaning the glassware.

The dehalogenation techniques employed were: (a) the Willson chlorinated hydrocarbon detector unit, both as a field unit and as a laboratory furnace unit; (b) the combustion furnace; (c) alcoholic potassium hydroxide; and (d) sodium biphenyl. In the case of the Willson unit and the other combustion units, the hydrochloric acid and chlorine were absorbed in an alkaline solution of sodium arsenite. The chloride ion was subsequently determined by mercurimetric titration. The procedure involving potassium hydroxide in isopropyl alcohol for the dehalogenation of trichloroethylene was used only to satisfy ourselves that the percentage recovery was as variable as is reported.[2]

The dehalogenation techniques described by both Liggett[3] and Bergmann and Sanik[4] involve the use of sodium biphenyl. The results reported by these authors were confirmed. However, the method for the preparation of sodium biphenyl was that of Liggett. Even though all batches prepared appeared to be dark green, some were found not to be stable enough to use with toluene. Most batch preparations were found to be satisfactory, if due precautions were taken to avoid air contact and if an excess of granular sodium was allowed to remain in the storage bottle. Fifteen milliliters of tol-

* Work performed under the auspices of the U. S. Atomic Energy Commission. Presented at the American Industrial Hygiene Association annual meeting on April 25, 1958, Atlantic City, New Jersey.

uene was found to be a maximum volume for the reaction with sodium biphenyl. The procedure is carried out as follows:

In a Liggett modified separatory funnel, place 15 ml of toluene and add 10 ml of the sodium biphenyl reagent (ethylene glycol dimethyl ether and toluene solution), which should remain green. After mixing, extract with 10 ml of water and allow the layers to separate. Drain the aqueous phase into a 100 ml volumetric flask and extract the organic layer with two portions of 5 ml of 3*N* nitric acid and one portion of 5 ml water. Combine the acid and water extracts in the volumetric flask, dilute to volume, and mix well. The analysis of the acid solution may be carried out by the mercuric thiocyanate colorimetric procedure or by the silver thiocyanate titrimetric procedure.

The mercuric nitrate colorimetric procedure of Bergmann and Sanik is simple and accurate; it depends on the success of the dehalogenation technique. The procedure outlined below is that described in detail by the authors:

Place 20 ml of each standard and air sample obtained from the dehalogenation procedure in 25 ml volumetric flasks. Add two ml of 0.25*M* ferric ammonium sulfate [$Fe(NH_4)(SO_4)_2 12H_2O$] solution in 9*M* nitric acid, followed by two ml of saturated solution of mercuric thiocyanate in ethyl alcohol. The solutions are mixed, made to volume, and again mixed. The per cent transmission is determined at 460 millimicrons in a 19 × 105 mm Coleman cuvette 10 minutes after color development. Water is used as a reference solution.

The above method has the advantage that any chlorinated hydrocarbon, once it has been dehalogenated, can be determined rapidly and accurately.

The mercuric nitrate titrimetric procedure of Domask and Kobe[5] was found to be very useful in determining the chloride ion in simple solution. However, the complex solution resulting from sodium biphenyl dehalogenation was turbid and caused the indicator to become adsorbed on the suspended matter. The technique was modified so that a single normality of the mercuric nitrate solution could be used in the calculations. This was accomplished using a pH meter during titration and controlling the final pH at the end point to within 0.1 pH unit at pH 2.6, with dilute sodium or potassium hydroxide. The starting pH was always three. Even though the mixed indicator recommended by the authors was used, the acidity was determined by the pH meter, and the color change was used only for preliminary acidification. The following procedure was used:

The samples received from a Willson chlorinated hydrocarbon unit, laboratory furnace combustion train, or sodium biphenyl dehalogenation technique are placed in 400 ml beakers. Dilute the solution to approximately 100 ml with water in a 400 ml beaker and add five drops of the mixed indicator (0.5 gm of diphenylcarbazone, 0.05 gm of bromophenol blue and 0.12 gm of xylene cyanole FF in 100 ml of 95 per cent ethyl alcohol). Insert a magnetic stirring bar and place on a magnetic stirrer. Titrate to the first yellow color with 0.1*N* HNO_3. Insert the pH electrodes and adjust the pH to exactly pH 3. Titrate with standard mercuric nitrate in nitric acid to a violet end point, using dilute potassium or sodium hydroxide to maintain the pH between 2.5 to 2.7

The silver thiocyanate titrimetric procedure is the standard Volhard method with the modification described by Liggett. The turbid or colored solutions that resulted from the sodium biphenyl dehalogenation were titrated more successfully with this method.

Sampling Methods

1. The Willson chlorinated hydrocarbon unit is used with a flow rate of one liter per minute. The platinum foil is maintained at red heat and the resulting gas absorbed in a sodium carbonate-arsenic trioxide solution. The absorption column is washed by filling ten times with water, and the washings are combined in a beaker for analysis.

2. Silica gel (16 to 17 gm) is placed in a U-tube and the contaminated air drawn through the tube at one liter per minute. The sealed tube is then held for analysis. This sample can be treated in either of two ways. The halogenated hydrocarbon can be thermally removed by hanging the tube in a wax bath and sweeping the halogenated hydrocarbon from the tube by air into a thermal dehalogenation unit or Willson unit. The second method is that of eluting the trichloroethylene with toluene. The toluene must be allowed to come into equilibrium with the silica gel before decantation (one hr). This is repeated and the combined toluene eluates analyzed by the Seto and Schultze method.

3. The contaminated air is sampled by bubbling through toluene at one liter per minute. A fritted glass bubbler is used with 75 ml of toluene as the sampling medium. This may be

TABLE I

Efficiency of Toluene for TCE Absorption

Single bubbler			Series of two bubblers			
μg TCE/ml	ppm	Corrected ppm*	μg TCE/ml	μg TCE in total sample	Efficiency (%)	ppm
29.64	69.4	71.3	31.48 1.03	3251	97	73.5
33.59	73.4	75.6	32.72 1.05	3377	96.9	70.0
31.12	75.2	77.5	33.34 0.75	3409	97.7	77.2

* Corrected to 100 per cent efficiency.

TABLE II

Silica Gel Absorption

Sampling method	Method of analysis	ppm TCE	
		Series I	Series II
Single bubbler	Seto and Schultze	79.0	81.6
SiO_2 with toluene elution	Seto and Schultze	66.9	78.4
	Bergmann and Sanik	64.47	77.18
Single bubbler following SiO_2	Seto and Schultze	0.0	0.0

TABLE III

Comparison of Two Analytical Methods

Calculated ppm TCE in chamber	ppm TCE Found	
	Bergman and Sanik method	Seto and Schultze method
17	13.24	12.97
30	32.02	29.98*
80	79.54	74.88*
140	151.53	134.64*

* The samples were diluted 1 to 10 with toluene for analysis and agreed in the case of the 30 ppm sample with the undiluted samples.

followed by direct trichloroethylene analysis by the Seto and Schultze method or dehalogenation by the sodium biphenyl method of Liggett.

Standard Air

A standard air of a known concentration was prepared by bubbling nitrogen at 0.2 liter per minute, through a series of bubblers containing trichloroethylene, in a water bath at 21° C. This was mixed in a 10 liter all-glass chamber with dry air to dilute the trichloroethylene to the desired concentration. The samples were taken at the end of the 6-inch diameter chamber where several stopcock-controlled ports were attached. The concentration of the trichloroethylene in the dynamic chamber fluctuated during the day but was constant during any series of sampling runs.

A second method of preparing a known concentration was to use a 15.5 cubic meter static chamber with glass windows. The walls and all metal surfaces were painted with an epoxy resin. A weighed amount of trichloroethylene was evaporated from a weighing bottle on a heated sand bath and the air mixed by a fan. The samples were drawn from the center of the room by a glass tube inserted through the walls of the chamber.

Evaluation Methods

In order to evaluate the various methods of analysis, it was necessary to establish the relative efficiencies of the various sampling methods and the consistency of the standard air as prepared. Because the Seto and Schultze colorimetric method was simple and appeared to give consistent results with laboratory spikes, this method was chosen as a reference method. Table I shows the results of an analysis of contaminated air by this method with both a single fritted bubbler and two bubblers in series. The flow rate was calibrated with a spirometer and the same setting on a Brooks Mite flowmeter was used. Values with both the single bubbler and the bubbler series were taken simultaneously.

The randomness of the results indicates a series of inconsistencies which were not completely controlled. The use of the figure 97 per cent for the efficiency of the toluene bubbler was confirmed with a series of samples from the static chamber. All of the results hereafter reported are the values found and not corrected to 100 per cent recovery.

When the silica gel U-tube was followed by a toluene bubbler, the silica gel eluted with

TABLE IV

Replicate Air Analysis

Methods	ppm
"Willson" + $Hg(NO_3)_2$	64.7
SiO_2 + Thermal Displacement + $Hg(NO_3)_2$	75.0 ± 10
SiO_2 + Toluene Elution + Fujiwara	72.0 ± 9
Toluene Bubbler + Fujiwara	73.77 ± 5.2
Naϕϕ + $Hg(SCN)_2$ + Colorimetric	72.39 ± 14.4
Naϕϕ + $Hg(NO_3)_2$ + Titration	Not feasible
Naϕϕ + $AgNO_2$ + Titration	High Conc. only

* Naϕϕ = sodium biphenyl.

toluene, and the toluene solutions analyzed, all of the TCE appeared to have been adsorbed by the silica gel for none of the toluene bubblers ever showed the presence of TCE. Elution of the silica gel with toluene gave satisfactory results; however, they were consistently lower than the toluene bubbler samples. The silica gel U-tube was filled with toluene and allowed to equilibrate for one hour and the toluene decanted into a 100 ml volumetric flask. The equilibration was repeated and then the silica gel was washed with toluene until a volume of 100 ml was received. Typical results are shown in Table II.

From this, it can be seen that the silica gel adsorption of approximately 80 ppm of TCE at one liter per minute is 100 per cent, and that the loss occurs in the elution of the TCE from the silica gel.

The Willson unit gave consistently lower results than the toluene bubblers. During the run, the toluene bubblers gave an average value for the standard air of 76 ppm TCE and the Willson unit gave 64.6 ppm TCE. The chloride ion was titrated by the mercuric nitrate procedure.

Results

Fifteen samples were taken from the dynamic system and analyzed by the Bergmann and Sanik method after dehalogenation by sodium biphenyl. The samples were also analyzed by the Seto and Schultze method. The chamber was operated to give a calculated trichloroethylene concentration of 77 ppm. The Bergmann and Sanik method gave 72.39 ± 14 ppm with high values to 88 ppm and low values to 49 ppm TCE, while the Seto and Schultze method gave an average of 73.77 ± 5.2, with high values to 81 ppm and low values to 52 ppm. No explanation is obvious for the discrepancy between the calculated value and the concentration found by analysis. Attempts were made to titrate these samples with the procedures previously mentioned, but the concentration of chloride ion in the final solution was below the limits of reliability of either method.

The static chamber was used to determine the most suitable range for the various methods of analysis. The chamber was cleared by forced ventilation prior to each test. The trichloroethylene was evaporated and allowed to mix for 15 minutes prior to sampling. The results shown in Table III represent duplicate analyses of the same sample with the two methods used in the previous test, and the average of three different samples.

Conclusions

Air samples taken with toluene bubblers can be analyzed with reliable results either by the controlled Fujiwara method of Seto and Schultze or by dehalogenation with sodium biphenyl and subsequent determination of the chloride ion by the mercuric thiocyanate method of Bergmann and Sanik, or a titrimetric method using silver nitrate. A summary of the results is shown in Table IV. Samples to be held for analysis, or by necessity shipped to the laboratory for analysis, may be taken successfully on silica gel and eluted from the silica gel, using toluene and analyzed as described above.

It has been the practice of this Laboratory to take the air samples with toluene bubblers and to determine the trichloroethylene by the controlled Fujiwara method and from this determine the need for further analysis. Should the samples be high, an aliquot is taken for dechlorination and a portion is used for the colorimetric mercuric thiocyanate method. If this is also high (above 5 mg per sample), the remainder of the dechlorinated aliquot is titrated by the silver nitrate method.

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Sampling and Analysis of Phenols in Air*

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PHENOLS IN water resources have long been of concern to sanitary engineers and water chemists, while phenol, the cresols and related compounds as air contaminants have similarly interested industrial hygienists for many years. This interest has been centered largely in the chemical industries, where such compounds are either synthesized or utilized as reactive intermediates. As a class of compounds, however, the phenols have not been too troublesome to the industrial hygienist, and certainly do not now constitute a major problem. This same statement is even more applicable to air pollution study, assuming that the near-complete absence of papers on the subject is a reliable criterion. It follows, then, that relatively few papers dealing with the sampling and analysis of phenolic compounds in air have appeared in recent times. By contrast, the general analytical literature of phenols is rather voluminous, and as is often the case, industrial hygiene can profit by the studies of others.

In the course of a study** on the occurrence of phenolic compounds in urban air, it became necessary to seek a method for total phenols sufficiently sensitive and accurate to yield useful data. Jacobs[1] presents several methods for total phenols as well as certain specific phenols, but most of these methods are not suitable for determining trace quantities present in the general atmosphere. Braverman, et al.[2], however, modified the p-aminodimethylaniline sulfate method to measure microquantities of phenol in the air of New York City, and reported concentrations in the parts per 10 billion range.

No attempt is made here, though, to completely or critically review all published methods for phenols. An excellent review covering methods published prior to 1949 may be found in U. S. Public Health Service Bulletin 190 by W. F. von Oettingen.[3] A search of the literature revealed that in the field of water analysis, methods had been developed and widely used for determining phenols in the parts per billion range, and these methods were accordingly considered for possible adaptation to air sampling. The American Public Health Association recommends the use of two colorimetric procedures in the current edition of Standard Methods.[4] The first of these uses Gibbs reagent, 2,6-dibromoquinonechlorimide to ultimately form a colored complex with phenols which may be spectrophotometrically measured. No description of the method will be made here, inasmuch as it did not prove to be the method of choice in our hands. The objections to its use include the excessive time required for full color development, and the failure of samples to yield colors similar to standards. Although the Gibbs method appears to have been the classic method of water analysis for many years, water chemists seem to favor discarding it in favor of the more recently developed colorimetric procedure utilizing 4-aminoantipyrine as the color-forming reagent. Our studies with this reagent have shown it to be quite suitable for air sample analysis, and its use in air pollution and industrial hygiene can be recommended.

4-Aminoantipyrine Method

The use of this reagent for phenols was first proposed by Emerson,[5] and has since been studied by Martin,[6] and Ettinger, et al.,[7] among others. The work of Ettinger, et al., was particularly thorough, and is recommended as a valuable source of information concerning the experimental justification for the various steps of the analytical procedure. These authors studied the effects of pH, temperature, order of addition of the reagents, and response of numerous phenols as well as other variables in arriving at the procedure recommended by them. Most recently, Mohler and Jacob[8] compared five methods for trace amounts of phenols in water and waste water, and included a critical evaluation of the 4-aminoantipyrine method in their comparision. In general, these authors list as advantages of the method ease and speed of analysis, reproducibility, applicability over a wide concentration range, and stability of reagents. The principal disadvantages noted are variations in the sensitivity due to pH differences, and failure of

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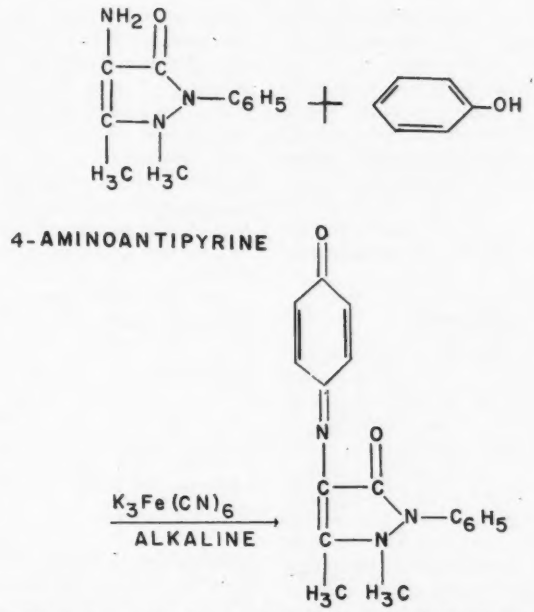

FIGURE 1. Typical equation for reaction of phenol with 4-aminoantipyrine.

the reagent to respond to para-substituted phenols. Figure 1 shows a typical equation[5] for the reaction between phenol and 4-aminoantipyrine, and makes clear the reason for lack of response to para isomers, when aryl, alkyl, carbonyl, or certain other groups are in the para position. The reaction will go with halogen, carboxyl, hydroxyl and similar groups in the para position, however, for these groups are removed. Considerably more information about the method is summarized in the paper, but is not sufficiently pertinent to warrant repetition.

Air Sampling

PARTICULATES

Air sampling for phenolic compounds may be satisfactorily performed in several conventional manners. At the very low concentration levels of air not specifically contaminated with phenols, the principal problem is collecting a sample of sufficient size to be analytically reliable. If particulates only are of interest, this may be accomplished by using flash-fired fiber glass filters, and a high-volume sampler such as the Staplex unit. At the usual sampling rates of around 50 cfm, a twenty-four hour sample will always yield more than enough phenolics for reliable measurement, and frequently a two-hour sample will be adequate. Other types of filter media may be satisfactory, but at low concentration levels, these have not been studied by us.

VAPORS

Phenolic vapors may be collected by various means, the most direct being absorption in alkaline solution. For this purpose 1*N* NaOH in standard impingers, midget impingers, or fritted absorbers has proven satisfactory, with collection efficiency approaching 100% in all instances. Distilled water can also be used as the collecting medium, if necessary, but if the samples are to stand some time before analysis it is well to emulate the water chemists and add a small amount of copper sulfate as a preservative. As reported elsewhere,[6] all samples of city air thus far analyzed show considerably more phenols in the vapor state than in the solid state, and as a result vapor samples need not be as large as the latter. Thirty minutes of sampling at the usual sampling rates for the several absorbers mentioned will ordinarily be sufficient, assuming conventional solution volumes. It should be realized that when phenol vapors are sampled by means of an absorber, both vapors, and particulates, to some extent, are being retained, so that more correctly total phenol is being sampled. In view of the high vapor-to-solid ratio cited, however, the contribu-

tion by the particulates is often negligible. The use of a Millipore filter prior to the absorber will, of course, assure a true vapor sample.

Adsorption on activated carbon is an excellent means of sampling phenolic vapors as well as other organics, but it is somewhat more difficult to remove the sample quantitatively for subsequent analysis. The method is especially valuable, however, when it is desired to sample for long periods of time, or when a sample of sufficient size to permit fractionation of individual compounds is needed.

Preliminary Treatment of Samples

Filter samples: The entire filter, or a measured portion of it, is placed in a conventional Soxhlet extractor and refluxed for several hours with reagent grade benzene. A blank should be run prior to commencing analysis of samples, taking an unused filter and the same quantity of benzene required for refluxing samples. (The quantity of benzene will vary with the size of the extractor and the boiling flask, and should be kept minimal.) The blank will ordinarily be negative, or quite small, but if elevated it is likely that the benzene is contaminated. In this event an adequate volume of benzene should be purified by shaking with 1*N* NaOH in a separatory funnel prior to use. Following the extraction of the filter samples, the benzene is transferred to a separatory funnel, filtering if necessary to remove dirt particles, and extracted three times with 10 ml portions of 1*N* NaOH. The alkali solution is heated to boiling, or until no further benzene odor is detectable, then treated as described under the section on Analytical Procedure.

Samples collected in 0.1N NaOH: These may usually be treated directly as described under Analytical Procedure, but in special instances where the air is known to be heavily contaminated it is well to refine the sample somewhat beforehand. This should be done, for example, if the method is to be applied to the analysis of exhaust gases or other process effluents. A suitable refining procedure, based on the preliminary screening procedure described in Standard Methods[4] is as follows:

Add 1 ml 10% $CuSO_4$ to the sample, and lower the pH to less than 4 with 10% H_3PO_4, using methyl orange as the indicator. (These and subsequent quantities are based on an initial sample volume of 100 ml. Proportionate quantities should be used for samples of differing volume.) Transfer the sample to an all-glass distillation apparatus, collect 90 ml of distillate, cool slightly, then add 10 ml distilled water, and continue distilling until 100 ml have been collected. Acidify the distillate with several drops of H_3PO_4 solution, add 1 ml $CuSO_4$ solution, and transfer to a separatory funnel. Add 30 gm NaCl, and extract three times with 10 ml of chloroform. Discard the aqueous phase. Shake the combined chloroform extracts twice with 15 ml portions of 0.1*N* NaOH. Dilute the combined alkali extracts to 50 ml, and heat until all chloroform has been removed. The sample is now ready to be redistilled and treated as described under Analytical Procedure.

Samples collected on activated carbon: Either all of the sample, or a weighed aliquot of it is placed in a Soxhlet extractor of suitable size and refluxed for several hours with benzene. Sample treatment is identical to that described for filters, except that it is more difficult to desorb carbon than to remove organic matter from a filter. It is probable that complete desorption is never achieved, but based on studies reported by Middleton, et al.,[10] a high percentage of organic matter is removed if refluxing is continued sufficiently long. It is ordinarily satisfactory to reflux samples of moderate size for about eight hours, and to assume that most of the phenols have been removed. If the benzene extraction is followed by another extraction using chloroform, ether, or some other organic solvent, more organic matter will always be removed, but in our experience only negligible amounts of phenolic substances are thus released.

Reagents

Reagents are prepared as described in Standard Methods,[4] and repeated here for convenience.

4-Aminoantipyrine solution: Dissolve 2 gm 4-aminoantipyrine in distilled water, dilute to 100 ml. Prepare fresh solution weekly.

Potassium ferricyanide solution: Dissolve 8 gm $K_3Fe(CN)_6$ in distilled water and dilute to 100 ml. Make fresh if solution darkens.

Ammonium chloride solution: Dissolve 50 gm NH_4Cl in distilled water and dilute to one liter.

Standard phenol solutions: Prepare master standard by dissolving one gram reagent grade phenol in one liter of water. An intermediate standard is prepared by diluting the master standard 1:100, so that 1 ml = 10.0 μg phenol. A dilute standard is made by a further dilution of 1:10 so that 1 ml = 1.0 μg phenol. The dilute standard is prepared fresh daily, or as needed.

Standardization of Phenol Solutions[4]

Bromate-bromide solution: Dissolve 2.784 gm $KBrO_3$ in distilled water, add 10 gm KBr, and dilute to one liter. Place approximately 100 ml

distilled water in a 500-ml glass stoppered Erlenmeyer flask and add 50 ml stock phenol solution. To this add *exactly* 10.0 ml bromate-bromide solution followed by approximately 5 ml of concentrated HCl. Swirl gently with flask stoppered. If brown color of free bromine does not persist, add bromate-bromide reagent in *exact* 10-ml portions until bromine color does persist. Stopper and allow to stand for 10 minutes and then add approximately one gram KI. Four 10-ml portions of the bromate-bromide reagent are required if the stock solution contains 1,000 mg phenol/liter.

Prepare a blank in exactly the same manner, using distilled water and 10 ml bromate-bromide solution.

Titrate both blank and sample with the 0.025*N* sodium thiosulfate using starch solution as indicator.

Calculate the strength of phenol solution by the following formula:

Mg phenol/liter = [(A x B) − C] x 7.835

Note: The factor 7.835 is based on using exactly 0.025*N* thiosulfate.

A = ml of 0.025*N* thiosulfate used for blank.

B = ml of bromate-bromide solution used for sample divided by 10.

C = ml 0.025*N* thiosulfate used for sample.

Analytical Procedure

After pretreatment, the samples, now in 0.1*N* NaOH, are adjusted to a volume of 100 ml by diluting with water or aliquotting, as needed. Add one ml 10% $CuSO_4$, lower the pH to less than 4 with 10% H_3PO_4 using methyl orange as indicator, and distill from an all-glass distillation apparatus. Collect 90 ml, cool slightly, add 10 ml distilled water, and continue until 100 ml have been collected. In the absence of knowledge concerning the phenol concentration of the sample, proceed using a 50 ml aliquot of the distillate, reserving the other half for a repeat determination if the concentration is too high. Prepare standards containing 0, 0.5, 1.0, 5.0, 10.0 and 20.0 μg phenol, using the appropriate volumes of intermediate or dilute solutions, and dilute to 100 ml. Other standard series, more suited to some samples, can be made, as indicated. Treat samples, blank, and standards as follows:

Add 2 ml NH_4Cl solution, and adjust the pH to 10.0 ± 0.2 with NH_4OH, using a pH meter. Add 1.0 ml 4-aminoantipyrine solution, mix, then add 1.0 ml potassium ferricyanide solution. Transfer to a separatory funnel, and after three minutes shake with three 5-ml portions of chloroform. Some of the chloroform will remain in the aqueous phase, so the combined extracts should be adjusted in volume to exactly 10.0 ml, or other known volume, and the absorbance recorded at 460 mμ in a spectrophotometer or filter photometer, using the blank as reference. Cells ranging from 1.0 to 5.0 cm in path length may be used, depending on the standard range of interest. For higher concentrations of phenol, the chloroform extractions may be omitted, and colored aqueous solutions can be measured directly, at 510 mμ.

Calculations

Standards are used to make a concentration vs absorbance curve from which the phenol content of samples is determined. A typical curve, based on data obtained with a B & L Spectronic 20, medium sized (¾ inch) cells is shown in Figure 2. Results are computed in conventional fashion, being sure to take into account the several aliquots which may have been used, to obtain the total quantity of phenol in the original sample. For particulate samples, results are usually expressed as micrograms per cubic meter, and for vapors as parts per million by volume at standard conditions. As useful conversion factors, 1 μg phenol/liter = 0.26 ppm, and 1 ppm = 3.84 μg/l. It should be noted that results are expressed in terms of phenol, whereas most commonly the samples are actually a mixture of phenols, and may not even contain phenol. In those instances where a specific phenol is known to be the pollutant in the air being sampled, standards should be made with this compound, and results expressed in terms of it.

Discussion

The procedure just described has been found to be reliable and not too difficult to carry out,

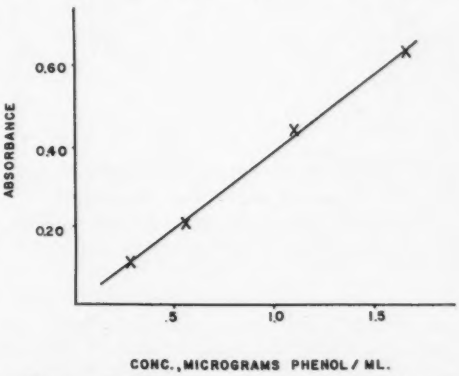

FIGURE 2. Standard curve, 4-aminoantipyrine method using B & L Spectronic 20 spectrophotometer.

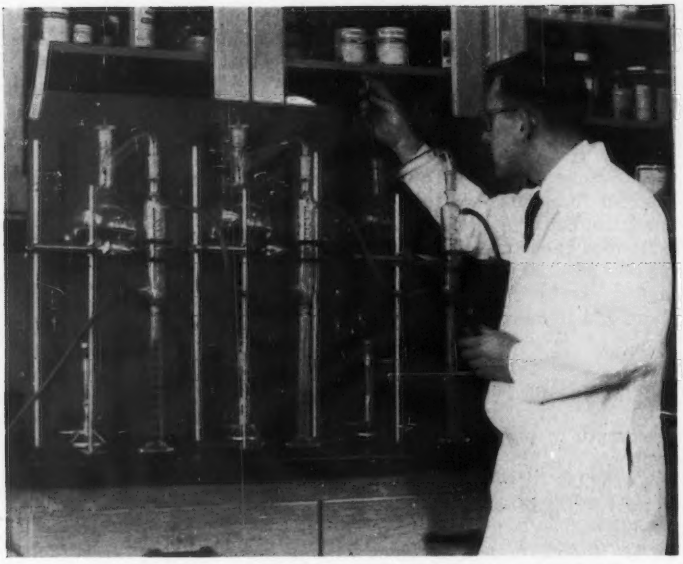

FIGURE 3. Battery of all-glass stills for distillation of phenols.

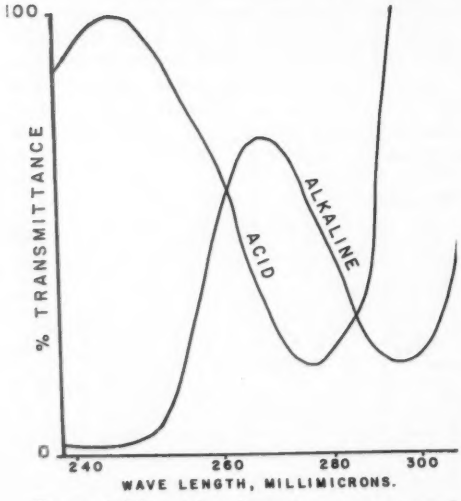

FIGURE 4. Ultraviolet absorption curve, p-cresol, made with Beckman DK-2 spectrophotometer.

even though a single sample would be quite time-consuming. Efficiency is gained, however, by analyzing a number of samples at once, utilizing several stills as shown in Figure 3. On several occasions analyses have been successfully made without distilling the samples. Although a considerable savings in time is effected, it is not recommended that all analyses be so performed. Various interfering substances, if present, will cause erroneous results.

It is important to bear in mind that the reagent does not yield a colored complex with most para-substituted phenols, and industrial atmospheres known to contain p-cresol or similar compounds must be evaluated by another means. It must also be realized that when expressing results as phenol, the true concentration of mixed phenolics as usually encountered will be greater than the reported value by an unknown factor.

UV Spectrophotometric Method

Under certain conditions, phenols may be determined rather readily by means of ultraviolet spectrophotometry. The method cannot be recommended for widespread use, however, for it requires an ultraviolet spectrophotometer, and preferably a recording instrument such as the Beckman DK-2. Measurement is based on the fact that all phenols exhibit characteristic absorption bands in the ultraviolet region, and that these bands shift as a result of pH changes. More specifically, phenols in acid solution absorb quite strongly in the 270 to 280 $m\mu$ region, and the spectra of these same solutions made alkaline undergo a bathochromic shift such that maximum absorption occurs at longer wavelengths. Figure 4 shows this shift for a typical phenol, and Figure 5 shows the same phenomenon for

phenolic substances collected from the atmosphere. The most precise manner of utilizing this shift was reported by Schmauch and Grubb,[11] who measure the absorption of specially-prepared samples at pH 5 and pH 12, then calculate the phenol content using suitable calibration curves. Mohler and Jacob,[8] in reviewing this method, point out its many advantages and recommend it as the most promising method for refinery wastes. Adaptation of the method to air sample analysis is not difficult, and samples collected by any of the means previously described can be analyzed, without basically altering the procedure. In view of the relative complexity of the determination, the original paper should be consulted, however, and no further discussion of it will be made here.

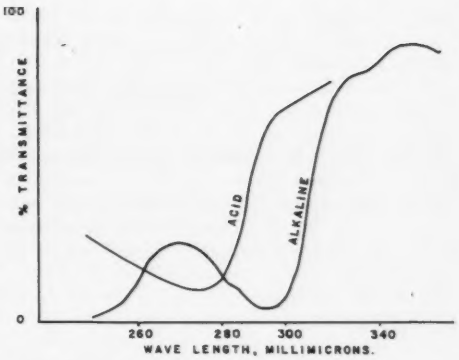

FIGURE 5. Ultraviolet absorption curve, phenols collected from atmosphere, made with Beckman DK-2 spectrophotometer.

Simplified Procedure

A simple, though less accurate, procedure may often be used to advantage, and if the sampled atmosphere contains a known phenol, the accuracy becomes quite acceptable. Samples may be collected by any of the means previously mentioned, and can then be refined to whatever extent the analyst may desire. For example, purification accomplished by the series of extractions and distillations already described can be elected, or extraction alone can be used to remove interfering hydrocarbons which might absorb at critical wavelengths. Without resorting to a combination of such operations as well as chromatographic separations, complete isolation of phenolic substances from the usual samples is difficult, and probably justified only as a research project. As a compromise, therefore, the following simple procedure is recommended for qualitatively establishing the presence of phenols, and for determining semi-quantitatively the amounts present.

Transfer the sample into benzene by extraction as previously described. Remove phenols from the benzene by extracting with three small portions of 0.1*N* NaOH. Combine the extracts, and remove all benzene by heating. Cool, and record the spectral transmittance (or absorbance) curve in the ultraviolet range. If the phenol concentration is too high, dilute with 0.1*N* NaOH until a satisfactory absorbance is attained. Acidify an aliquot of the solution by dropwise addition of 10% HCl, making pH measurements with pH test paper and a glass rod, and again record the ultraviolet spectrum. A shift in the alkaline solution absorption maximum in the 290 $m\mu$ region to the 280 $m\mu$ region, when acid, as seen in Figures 4 and 5, is good confirmation of the presence of phenols. For quantitative analysis, the absorbance of the alkaline solution in the 290 $m\mu$ region is measured, and compared to curves made from known phenol solutions treated in similar fashion. It is apparent that exact control of sample volume and aliquot dilutions is necessary for quantitative analysis, although the actual volumes used may vary. If a recording spectrophotometer is not available, the method loses much of its attractiveness, but a conventional spectrophotometer can, of course, be used, making measurements at several points to establish the wavelength of maximum absorption. In either case, non-phenolic compounds which absorb at the wavelengths measured constitute an interference. When the complete spectral curve is presented, however, the purity of the sample becomes more readily apparent, as judged by comparison with known phenolic curves.

It is clear that the ultraviolet method as here presented is normally only semiquantitative if samples of city air, auto exhaust, combustion products, or similar materials are being analyzed. It should be equally apparent, though, that many of the organic analyses made on similar samples are also compromises. All known methods for total phenols will certainly yield results that are not absolute in nature. For the industrial hygienist concerned with specific compounds or mixtures, however, it is very likely one of the best methods available.

Summary

Two methods for the sampling and analysis of phenols in air have been developed. A colorimetric method, using 4-aminoantipyrine as the color-forming agent is recommended for general

usage, inasmuch as its widespread use by water chemists has made it one of the more reliable methods available.

A more rapid procedure is based on the measurement of an absorption band in the 290 mμ region, by means of an ultraviolet spectrophotometer. This band is characteristic of most phenols in alkaline solutions. Qualitative confirmation of the presence of phenolic compounds can also be made by comparison of the ultraviolet absorption curves of acidic and basic solutions of samples.

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South African Conference

FOUR AMERICANS eminent in industrial hygiene and occupational medicine were among the 15 representatives from seven countries meeting in Johannesburg, South Africa, February 9 through 21 at a conference on pneumoconiosis. They were Theodore F. Hatch, Graduate School of Public Health, University of Pittsburgh; Eugene P. Pendergrass, M.D., University of Pennsylvania Medical School; O. A. Sanders, M.D., Marquette University School of Medicine; and A. J. Vorwald, M.D., Wayne State University College of Medicine. The conference was held at the invitation of the Pneumoconiosis Research Unit of the South African Council for Scientific and Industrial Research. The theme of the conference was twofold: (1) a critical review of the present knowledge of the etiology, pathology and diagnosis of pneumoconiosis; and (2) the program for future research, particularly in prevention.

Mr. Hatch presented a paper on "Respiratory Dust Retention and Elimination." Dr. Sanders gave two papers, "Radiological Appearances of the More Common Pneumoconioses and of Other Conditions Which Simulate Them" and "The Effect of Continuing in Original Dusty Occupation on the Progression of Pneumoconiosis." Dr. Vorwald was Vice-President of the conference, chairman of one session, and author of two papers. His talks were "The Bioassay of Dust with Particular Reference to Experimental Methods" and "The Significance of Submicroscopic Particles in the Pathogenesis of Pathology of Silicosis."

The Occurrence of Phenols in Air and Combustion Products*

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PUBLIC CONCERN with the causes and effects of air pollution has resulted in increasing scientific interest in the nature of the chemical mixture present in the atmosphere. Large sums of money are being expended in an effort to analyze this mixture in the belief that full and complete knowledge of its composition will provide the means for eventually solving the many problems created by it. This approach must be considered basically sound, in view of many past scientific successes in other fields, and it provides the principal justification for a study** such as reported here.

Numerous investigators have dissected the atmosphere and its undesirable additives, with the result that enormous amounts of information are already available when new research is contemplated. It is nonetheless true that even a very thorough search of the literature will often fail to yield appreciable information on certain specific subjects. This proved to be the case with respect to phenols in the general air. Our interest in this subject was originally stimulated by a study of localized air pollution in the vicinity of a plant which emitted phenolic substances to the atmosphere. These emissions proved to be quite objectionable, and sampling of the air in various locations was accordingly undertaken. To interpret the results obtained, effort was made to find data relating to normal levels of phenolics present in the air of cities, or in manufacturing areas, but such data proved to be almost non-existent. In a 1955 report,[1] the Air Pollution Foundation published limited data to show that from 3 to 7% of the organic substances extractable by benzene from particulate matter collected in the Los Angeles area consisted of phenols, which were not otherwise identified. By calculation from data presented, these proportions would amount to approximately three micrograms of phenols per cubic meter of air. Noting that the percentage of phenols varied with the sampling location, the Foundation report suggested that further investigation of the reasons for these differences was indicated.

More recently Braverman, et al.,[2] reported finding phenol in the parts per 10 billion range in the air of New York City. Other publications describing the total organics present in city air, usually as particulate matter, or the numerous fractions into which they may be divided are readily found, but further breakdown into phenols has seldom been reported.

The data to be reported in this paper resulted from a study, the objectives of which were threefold: to determine whether phenols were commonly found in urban air, and to what extent; to establish qualitatively their chemical nature; and finally, to observe what effects, if any, these substances might have on experimental animals. As a corollary, it was considered desirable to attempt to establish the likely sources of whatever compounds were found. Accordingly, methods of sampling and analysis were devised, and a sampling program undertaken.

Sampling and Analytical Procedures

Several means of collecting suitable samples were utilized, but the data presented were based on samples collected by either of two methods. Particulates were collected on flash-fired fiber glass filters, using high volume samplers, while vapors were collected in impingers or fritted absorbers containing 1*N* NaOH solution. A modification of the 4-aminoantipyrine procedure for phenols in water was used to determine the total phenol content of the samples. Confirmation of the presence of phenols in the samples was also made in some instances by an ultraviolet spectrophotometric procedure. Complete details of the sampling and analytical procedures are given in a previous publication.[3]

Phenols in City Air

The principal location at which general air samples were taken, chosen primarily for convenience, was the Wayne State University College of Medicine, Detroit, Michigan. The building

* Presented at the Annual Meeting of American Industrial Hygiene Association at Atlantic City, New Jersey, April 24, 1958.

** This investigation supported by a grant from the United States Public Health Service.

TABLE I

Concentrations of Phenol in Air at Principal Sampling Location

(micrograms per cubic meter)

	Particulate	Vapor	Ratio (V/P)
Minimum	0.0044	1.13	
Maximum	0.2440	7.82	
Mean	0.0693	4.29	62.0

TABLE II

Concentrations of Phenol in Air at Selected Locations

	Medical School area		Street samples moderate traffic		Heavy chemical industrial area		Phenol-emitting plant area	
	$\mu g/m^3$	ppb	$\mu g/m^3$	ppb	$\mu g/m^3$	ppb	$\mu g/m^3$	ppb
Minimum	1.13	0.3	8.5	2.2	11.7	3.0	255.	66.3
Maximum	7.82	2.1	41.4	10.8	36.7	9.5	988.	256.9
Mean	4.29	1.2	19.0	4.9	20.3	5.3	566.	147.2

TABLE III

Phenol Concentrations in Air Near an Industrial Plant Emitting Phenol

(micrograms per cubic meter)

	Particulate	Vapor	Ratio (V/P)
Minimum	0.31	255	
Maximum	1.77	988	
Mean	0.81	566	699

is located near the downtown area, and enjoys the dubious distinction of being in an area where the air is generally somewhat dirtier than in outlying areas. Sampling was conducted on the roof, nine stories up, rather than at street level, but again, only for convenience. Particulate samples were ordinarily taken for a 24-hour period, or in some instances over a weekend. Vapor sampling periods were shorter, averaging about four hours each.

The results of several hundred samples, taken over a period of more than a year, are shown in Table I. If the mean value for particulates, 0.07 micrograms per cubic meter ($\mu g/m^3$), is compared to the value previously cited by the Air Pollution Foundation study, it is seen to be only about one fortieth as high, a somewhat improbable situation. It is likely that different analytical methods were used, and it would be very interesting to see a comparison of phenol levels in the two cities based on identical methods.

When the mean value for phenolic vapor concentrations, 4.29 $\mu g/m^3$ is converted into parts per billion (ppb), the resulting figure, just over 1 ppb, is seen to be in general agreement with the range expressed by Braverman, et al.[2] In this instance our figures appear to be the higher of the two, but as before, the differences may well be attributable to analytical procedures.

Of most interest is the very high ratio, 62:1, of phenols in the vapor phase to those found in the particulates, recognizing, of course, that the actual quantities are not great in either case. The literature of organic vapor phase analyses of atmospheric pollutants is quite sparse, compared to that pertaining to organics in the particulates, so that it cannot be said that this phenomenon is the rule, nor that it is atypical. It is possible that phenolics, originally collected as particulate matter on filters, are volatilized to some extent during the sampling period, but other evidence indicates that most of the phenol found is truly in the vapor phase. Activated carbon filters, for example, when used for sampling, give results comparable to those obtained by other methods.

On a much more limited basis, samples have been collected at numerous other locations in the Detroit area. The exact locations are not pertinent here, but may be summarized as being on various streets where automotive traffic was moderate in volume, near industrial areas, or simply in business or residential areas. It had been anticipated that several industrial areas would show elevated phenol levels, and in one such area, the average of relatively few samples was about five times that found at the principal sampling site. These data are summarized in Table II, in the column entitled, "Heavy Chemical Industrial Area". In this same table, street samples collected from a moving car in moderate traffic are also seen to average about five times the base value. Both sets of data were obtained from samples collected in alkaline solution, and presumably are representative of vapor concentrations, although vapors and particulates were not separated.

In contrast with these data are those shown in Table III, earlier referred to as originating from a phenol-emitting industrial plant. The phenol concentrations are seen to be considerably higher in both the solid and vapor phase, and the vapor to solid ratio is about ten times higher than occurs in normal air. Because of the proximity of the samples to the source, where the phenols are probably vapors when discharged, this ratio is not surprising.

Phenols in Combustion Products

The products emitted to the air as a result of combustion of common fuels, refuse, etc., were naturally suspected of being logical sources of phenolic compounds. The work of Tebbens and his associates[4] has proven conclusively that substantial quantities of phenols are formed when various fuels are incompletely burned under controlled laboratory conditions. Our sampling was limited to the three sources of combustion products assumed to be most common in Detroit; namely, domestic gas furnaces, oil furnaces, and automotive exhaust. Sampling was again quite limited, and intended only for range-finding purposes. In the case of automotive exhaust sampling, absolutely no attempt was made to control the almost limitless number of variables which such sampling can entail. More specifically, the samples were collected from the tailpipes of two different cars of respectable vintage, with the engines idling. The oil and gas furnaces were in good operating condition when samples were taken, but not specially adjusted in any way. A summary of all results is presented in Table IV.

The most unexpected finding from this series of samples was the relatively low phenol content of the oil and gas furnace effluents. These concentrations are not greatly higher than the general air levels, and if the data are representative of the many thousands of furnaces in the city, then domestic gas and oil consumption does not seem to be an important source of phenolic compounds.

The automotive exhaust samples proved to be entirely different, however, being higher by several orders of magnitude than either of the furnace exhausts. Vapors predominate to an overwhelming degree, as may be seen from Table V,

TABLE IV

Phenols in Combustion Products

(micrograms per cubic meter)

	Domestic oil furnace	Domestic gas furnace	Automobile exhaust
Minimum	6.9	32.7	5,600
Maximum	19.3	42.7	25,300
Mean	13.1	37.7	13,600

TABLE V

Phenol Concentrations Found in Samples of Exhaust Gases from Idling Automobiles

(micrograms per cubic meter)

	Particulate	Vapor	Ratio (V/P)
Minimum	2.65	5,600	
Maximum	11.70	25,300	
Mean	8.10	13,600	1,675

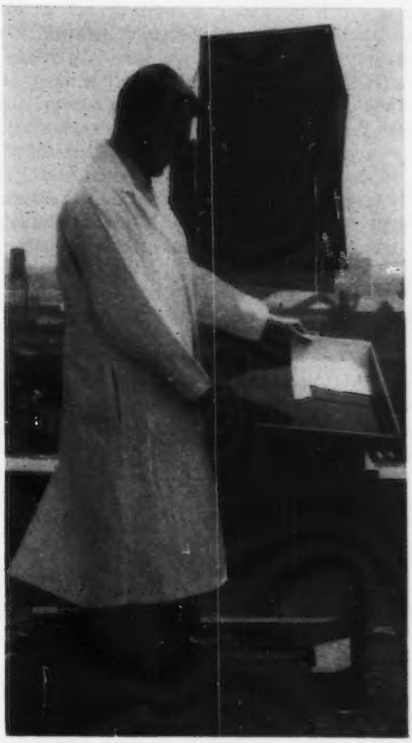

FIGURE 1. Photograph of high-volume sampler located on roof of Medical Science Building.

FIGURE 2. Sampling apparatus for collecting phenolic compounds from automotive exhaust.

with a ratio of vapor phenol to particulate phenol approaching 2000:1. These samples were removed directly from the hot exhaust stream, so it does not seem illogical that this situation should exist. It would be very interesting to observe the fluctuations in total phenols emitted under other conditions of engine operation. Most probably the concentration would decrease as combustion efficiency improved. It is likely that individual gasolines would also cause large variations, for not only are phenols formed as a result of combustion, but the unburned gasoline itself may contain appreciable quantities. The only sample of gasoline analyzed by us contained less than 20 ppm phenols, but Murray[5] indicates that gasolines may contain substantially larger quantities.

Discussion

In view of the results just presented, it can be said that the general air of Detroit, and very likely of most cities, contains a small but detectable quantity of phenolic compounds, present largely as vapors, but also found in the particulate matter. Our qualitative analytical studies to date indicate that the composition of the particulates is considerably different from that of vapors, but it is premature to attempt a description of the actual compounds involved. Circumstantially, the automobile appears to be the principal contributor of such phenolics as are found, but sampling has admittedly not been so complete as to preclude other major sources.

It seems justified to continue the efforts being made to identify the specific compounds present in both the air and exhaust products, and such work is in progress. The need to obtain larger samples is always great, because the demonstrated concentration levels do not yield very much purified phenolic matter. In an effort to obtain large quantities of particulates, an industrial blower rated at 800 cfm has been used to draw air through approximately three square feet of flash-fired fiber glass filters, composed of overlapping sheets 8 x 10 inches. This high-volume sampler, located on the roof of the Medical Science Building, is shown in Figure 1. In practice, with filters in place, the actual air flow is about 400 cfm, and decreases as the filters become loaded.

Large volume vapor samples have been collected by adsorption on activated carbon, with sampling rates of around 50 cfm. Some of these samples have been taken in air previously filtered by the large volume sampler so that particulates do not interfere, even though activated carbon is not particularly efficient in collecting particles. These samples, obtained during a several-day or week period, are considerably larger than could readily be obtained by any other means. As described elsewhere,[3] the adsorbed vapors can be removed quite effectively by extraction procedures.

A simple caustic scrubber has been used to remove the bulk of the phenolics and other acidic matter from automobile exhaust. The unit, as seen in Figure 2, is simply a plastic column, packed with Raschig rings, which are constantly wetted with recirculated strong NaOH solution. It is quite effective in removing phenols, as determined by sampling its effluent gases, and it imposes very little resistance to the passage of exhaust gases under idling conditions.

With samples such as are obtained by the foregoing methods, it is possible to isolate relatively large fractions of tarry substances with distinct phenolic odors. These fractions defy breakdown, but utilizing chromatographic techniques, among others, some progress is possible, and it is hoped that more complete isolation of individual substances will eventually result.

Summary

Phenolic compounds have been found to be present in the air of Detroit, both as vapors and as part of the particulate matter. The concentration levels are quite low, averaging less than 0.1 microgram per cubic meter in the particulates, and about 4 micrograms per cubic meter, (1 ppb) in the vapor phase. Small quantities of phenols were present in domestic gas and oil furnace discharges, and relatively large quantities were found in the exhaust products from idling automobile engines. Automotive exhaust concentrations averaged 13.6 milligrams per cubic meter, with virtually all phenols being present as vapors. Additional studies are in progress to identify specific compounds present in the general air and in combustion products.

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The National Conference on Air Pollution

THE NATIONAL CONFERENCE on Air Pollution, held in Washington, D. C., November 18 to 20, represented the first attempt on a national basis to bring together the many groups whose cooperation will be essential if the quality of the nation's air is to be conserved.

The Conference, called by Dr. Leroy E. Burney, Surgeon General of the Public Health Service, was convened to assess the current status of knowledge on air pollution and to outline practicable future programs, delineating specific responsibilities for all groups interested in air pollution and its control.

Nearly 1,000 representatives of municipal, county, state, and federal government agencies, universities, and principal scientific, voluntary and civic groups heard Dr. Burney, in his opening presentation, challenge the Conferees to "be as flexible as the enemy" in dealing with the air pollution problem. He noted that the air respects no boundaries—geographical, political, or disciplinary.

Other highlights of the plenary sessions of the Conference included speeches by Dr. Herman E. Hilleboe, New York State Health Commissioner, Dr. Chauncey D. Leake of Ohio State University, representing the American Association for the Advancement of Science, and Senator Thomas H. Kuchel of California, the author of the Federal Air Pollution Act. A panel of leading scientists presented a symposium on the status of current knowledge, and a second panel composed of Mayor Raymond Tucker of St. Louis and four spokesmen of major industrial associations discussed accomplishments in air pollution control.

Recommendations were formulated by the six discussion groups into which the Conference divided, and presented to the group as a whole. The following were of particular interest:

(1) The extension and expansion of the Federal Air Pollution Act with the elimination of the expiration date and appropriation ceiling;

(2) Increased attention to problems of recruitment and training of qualified persons to meet the challenge of modern air pollution problems;

(3) The expansion of research to determine the health effects of air pollutants;

(4) Additional research in devising effective control methods for various types of emissions of air pollution, with particular attention to the problems of automobile exhausts;

(5) An endorsement of the policy contained in the Federal Air Pollution Act in regard to the assignment of responsibilities to state and local air pollution control agencies, as well as industry and other institutions in formulating and carrying out air pollution abatement programs;

(6) Increased research to develop more effective and economical instruments and methods for monitoring and analyzing pollutants;

(7) Increased attention to education of the public on air pollution.

The broad coverage given to the Conference by the press, television, and radio clearly demonstrates the growing concern of the public in matters of air pollution. Understandably, a majority of this coverage was given to the highly controversial subjects of air pollution's impact on human health and the control of automobile exhaust emissions.

Arthur S. Flemming, Secretary of the Department of Health, Education, and Welfare, assured the Conferees that the Department would implement their recommendations to the greatest possible extent. He expressed his intention to work immediately for the extension of the Federal Air Pollution Act.

In the concluding plenary session of the Conference, a two-hour "Open Forum" was conducted, during which participants took the floor and commented, explained, or queried on various subjects pertinent to the Conference. This was culminated by a summary of the main points raised during the three days of meetings, by Martin Agronsky, nationally-known radio news commentator.

Status Report to the Nation*

L. E. Burney, M.D., Surgeon General, Public Health Service,
U. S. Department of Health, Education, and Welfare

I AM delighted to welcome you to this National Conference on Air Pollution. I want to thank each of you personally for giving three days of your busy life to a discussion of the air pollution problem. I believe sincerely that the urgent need for such a discussion justifies this imposition. We are witnessing a dynamic transi-

* Opening address at the National Conference on Air Pollution, U. S. Public Health Service, Sheraton-Park Hotel, Washington, D.C., November 18, 1958.

tion in our environment. The new world we are creating—higher standards of living, more comfortable, safer from communicable diseases—brings with it new problems which will not wait for leisurely solution. They demand immediate readiness on the part of persons representing a great variety of disciplines and skills, a readiness based on mutual knowledge and mutual confidence.

Air pollution is one of these problems. For this reason, we have brought you together. If our sponsorship of this Conference enables all of you to learn from each other—if in this sense we can act as a catalyst—we shall feel that our efforts have been successful.

In the presence of so many chemists I should add that we do not intend to fulfill the complete definition of a catalyst, as an agent which accelerates a reaction while remaining unchanged. We expect to enter fully into the reaction and to be improved by our participation.

My assignment is listed in the program as a "Status Report to the Nation." Actually, the findings of the Conference as a whole will constitute a Status Report, consolidating information on existing status and sharpening the perspective for the future.

Therefore, my talk will be designed to take its place as one portion of this total "Status Report." I shall report on the current status of the Public Health Service program in air pollution, after approximately three years of operation under Public Law 159 of the 84th Congress—what we have done and what we have learned. We expect you to tell us what the logical course of action seems to be in the future. This does not mean that we have no ideas of our own, but that we want a synthesis of opinion on the role of each of us in this growing problem of contemporary life.

Public Law 159, enacted by Congress and signed by President Eisenhower in 1955, is in itself a manifestation of what I consider to be the most significant single fact in the air pollution picture—the rising tide of public interest in the quality of our nation's air. The attendance of many of you here today is another evidence of this concern. Until a few years ago, air pollution was almost exclusively of interest to the professionals in the field.

As of today, the problem has emerged into public consciousness from coast to coast. This has been sparked by the development of acute situations and the growing realization of the increasing potential for air pollution in our cities. The recent action by the Governors' Conference in calling for a report on various types of State legislation available for adoption, and the recently expressed interest of the Conference of Mayors, indicate that our highest officials at the state and local levels are feeling this increase in public awareness. In the past two years, 11 different states have passed initial laws or strengthened existing air pollution legislation.

Unmistakably, the informed people in our nation are no longer taking for granted the air we breathe. They are rejecting the old maxim that a prosperous city is necessarily a dirty city. However, in only a few places has this attitude been accepted by the public to the extent that it has demanded preventive actions. The public as a whole still needs to ask several searching questions about air pollution. What is it doing to us? What is it costing us? Just how inevitable is it?

Above all, the people should ask what it is doing to their health. President Eisenhower, in his special health message to Congress in January 1955, struck the keynote when he said: "As a result of industrial growth and urban development, the atmosphere over some population centers may be approaching the limit of its ability to absorb air pollutants with safety to health."

We need not look for nation-wide epidemics from air pollution. We have been alerted by severe outbreaks both within industrial establishments and in community-wide smogs under certain atmospheric conditions. And now, after several years of closer observation, investigators are finding a definite association between community air pollution and high mortality rates due to cancer of the respiratory tract, including the lung, cancer of the stomach and esophagus, and arteriosclerotic heart disease.

In addition to these more serious problems of personal health, we are confronted now with many troublesome manifestations of air pollution—acute nuisances, plant damage, reduced visibility, odors and economic blight.

The law directs the Public Health Service to conduct and support research and to provide technical services to state and local governments and to private agencies. All of our activities in the air pollution field can be classified under these two headings of research and technical services.

In an area so vast, complex and relatively unexplored as air pollution, the greatest need has been to learn. Consequently we have devoted a great majority of our resources—about 80 per cent of the $12.5 million thus far appropriated—to research. The remaining 20 per cent of our budget supports activities classified as technical assistance, including consultation services, assignment of personnel on request to help with specific problems, demonstration and training projects, and others.

It would not be possible for me to describe in detail at this time the many research projects

presently underway with Federal and other support. A number of the papers which you will hear and discuss in your group sessions are based on federally-sponsored research, a fact which gives me great satisfaction and pride. I shall attempt only to indicate the broad general lines along which investigation is proceeding.

The goal of research on the health effects of atmospheric pollution can be simply stated: to determine the conditions under which toxic substances in the community atmosphere affect human health adversely, and the measures which must be applied to prevent adverse effects.

But with this statement of purpose, simplicity stops. The investigator is confronted by a seemingly infinite variety of polluting materials, reacting in the giant test-tubes of air above our cities. Also, he is searching for effects, not in relation to one disease with one specific cause but rather in relation to a large number of diseases, of multiple etiology, many of which are not in themselves clearly understood.

Medical research in this field includes both epidemiologic and laboratory studies. Comparing mortality and morbidity data with various indices of air pollution, we are finding interesting parallels; cities with the heaviest pollution loads tend to rank high in death rates for a number of diseases.

The relationship of cancer to atmospheric pollution, for example, is being explored. We know that cancer-producing agents are in the air we breathe. Cancers can be produced in animals using concentrates of urban smog. We know that lung cancer death rates in the largest cities are twice as high as those in non-urban areas. The case has not yet been proved, but the weight of circumstantial evidence grows heavier as research progresses.

A follow-up study on the population of Donora, Pennsylvania, where a week of smog in 1948 caused 20 deaths and widespread illness, shows that the people who were made ill by the smog, in general, have had poorer health and higher mortality rates these past 10 years than their neighbors who were unaffected by the episode, even though air pollution in Donora has been substantially reduced.

Laboratory experiments are yielding significant information on a number of specific pollutants which occur in community air. One of these, ozone, causes scarring of the lungs in animals which breathe it in sub-lethal doses over a period of months. Other experiments indicate that ozone may have an effect on the enzyme system as well as the respiratory tract and that aerosols aggravate the harmful effects of sulfur dioxide. It has been proved also that sulfur oxides, in concentrations sometimes found in community air, make breathing more difficult for human beings.

The National Air Sampling Network is now approaching a coverage worthy of its name. This plan for systematic measurement of air pollution depends upon the voluntary action of states and cities. Since January 1, 1957, the cooperating agencies have been using uniform sampling methods. At present, 180 cities and 51 non-urban areas have sampling stations, all manned by state and local personnel. Every state and territory has at least one urban and one non-urban sampling site. The Public Health Service has provided the equipment, established the procedures, and is analyzing the samples. It is important to note that seven states have established their own sampling networks giving more intensive coverage than the National Network is equipped to do.

Thus far the National Network measures and analyzes only particulate matter, solid particles and liquid droplets in the air. The need to include measurements of gaseous pollution is recognized, and will be met as technical and economic problems are overcome.

We recognize that a country as large as ours requires much larger resources than are available at the present time to sample and analyze air pollution on an adequate scale. The National Air Sampling Network is a good foundation for future expansion and refinement.

The Sanitary Engineering Center at Cincinnati is conducting many other studies in the engineering and physical sciences. They deal with measurement of pollutants at the source, behavior and dispersal of pollutants in the atmosphere, their various effects on vegetation and structural materials, and methods of control. The role of the automobile engine as a source of air pollution is under study. Some of our most valuable work is being done in improvement of equipment for continuous monitoring and in refinement of analytical methods.

The Public Health Service is collaborating with other federal and nonfederal agencies in research areas. For example, the U. S. Weather Bureau is clarifying the conditions of dispersal of pollutants, and has improved the accuracy of prediction of air pollution build-ups. The U. S. Bureau of Mines has developed and applied methods of analyzing automobile exhaust gases.

A project now underway in Nashville, Tennessee, combines medical and engineering studies in a manner which may establish a pattern for future investigations. We are studying air pollution levels in various parts of the city by intensive sampling, and at the same time conducting an epidemiologic study based on place and duration of residence within the city. Among the health

data recorded are cause and frequency of mortality, incidence of various diseases, and presence of carbonaceous dust in the lungs. Thus we are attempting to pinpoint pollution's effect on people's health where they live.

Control of air pollution demands not only additional knowledge through research but also more adequate resources, both in personnel and in material, at state and local levels. The Public Health Service has initiated action to help fulfill these needs. We receive many requests for technical assistance, ranging from limited consultation to large-scale participation in projects such as state and municipal air pollution surveys. We meet these requests to the extent of our capabilities, and supplement direct assistance by means of grants for demonstration projects.

Training courses are offered by the Sanitary Engineering Center, both in Cincinnati and in the field. More than 900 persons took part in these courses during fiscal year 1958, and the total for 1959 should be considerably higher. Interestingly, personnel from industry make up a higher percentage of the enrollees each year. It is encouraging that at least 14 universities are now offering graduate courses for advanced degrees in subjects related to air pollution, most of these having been established with Public Health Service grants.

Before closing, I should like to return to the broader problems of environment and health, of which air pollution and its control is one part. A few minutes ago, referring to the circumstantial evidence relating cancer to atmospheric pollution, I remarked that the case has not yet been proved. This legal metaphor is frequently used. I submit to you that it is misleading.

In law, the suspect is innocent until his guilt has been proved beyond reasonable doubt. In the protection of human health, such absolute proof often comes late. To wait for it is to invite disaster, or at least to suffer unnecssarily through long periods of time.

Many years ago, before anyone had seen a germ or positively identified a single causative agent of epidemic diseases, far-sighted leaders observed the association between epidemics and filth. Wherever they had sufficient foresight to act on this circumstantial evidence, they made striking progress. Cleaning up the city filth resulted in better health. Years later they found out why.

I suggest that our present position in respect to contemporary health problems, especially those relating to the urban environment, may be parallel to that of Pasteur's predecessors.

The City is the great sociological fact of mid-century American life. All of us have seen the population statistics. All of us have read the predictions calling for gigantic super-cities in the immediate future: a solid urban complex from Boston to Washington and perhaps from Portland to Norfolk on the Atlantic seabord; a similar unbroken mass from San Diego to San Francisco on the Pacific; a third megalopolis along the southern shores of the Great Lakes.

Another index of our growth is the increase in our national output. The gross national product is doubling every 17 years, an almost unbelievable acceleration spurred by an $8 billion annual investment in research. And the more we produce, the more problems we create in terms of wastes to be disposed of safely.

Finally, and perhaps most significantly of all, our new world differs from the old not only in degree but also in kind. Today we are dealing with processes and products which were unheard of prior to World War II. In ten more years, still more new substances will have been added to our environment. I need only refer to a few examples —the petrochemicals and other synthetics, the soaring future of nuclear technology and high energy fuels.

This, then, is the new environment we are creating. Are we ready, as professionals and administrators, to solve the problems it produces?

"The wind bloweth whither it listeth." Air—and therefore polluted air—respects no boundary lines, geographic, political, professional, or disciplinary. In our common struggle against air pollution, are we as flexible as the enemy? Here and there, yes.

Cities are banding together to form county-wide air pollution control districts. Counties are merging their resources where it is evident that they can be more effective by doing so, as in the San Francisco Bay Area. The Interstate Sanitation Commission covering the metropolitan area of New York City demonstrates that state governments can plan and act together. Work between Americans and Canadians in the Detroit-Windsor area is a fine, but little-known, example of international cooperation in the interest of human health and well-being.

Can we in the United States be equally flexible in regards to the less tangible but sometimes more stubborn boundary lines that separate profession from profession, special interest from special interest? I believe that we can.

The problems that come as by-products of our almost unbelievable material progress demand everybody's skills and knowledge. More than that, they demand genuine cooperation. We can no longer ask, "Who's going to be in charge?" or "Who's going to get the credit?" We must ask, "How can we most effectively work together?"

Nor can we ask, "Can we afford to clean up the air?" We cannot afford not to. It costs cities more to endure dirty air than to apply the controls we now have. Controlling air pollution will cost big money, but it is an essential investment.

Assuredly we all have the same goal—a safe and healthful environment in which everyone may enjoy the fruits of progress.

Your presence here, as representatives of so wide a variety of interests and competencies, is a heart-warming assurance to me that we can—we will—meet the challenge of air pollution.

Reports and Recommendations of Discussion Groups†

Group A—Extent of Air Pollution

Where do we stand in our knowledge of the identity and quantity of pollutants in community atmospheres?

This question is concerned with our ability to apply quantitative measures to pollutants in the atmosphere, rather than to how effectively this ability has been applied to measurements across the nation. The group of discussants devoted their principal attention to problems concerned with man-made pollutants of a chemical nature rather than with airborne bacteria, pollens and similar viable pollutants of natural origin. They recognize, however, that these latter pose important problems that need further consideration.

In identifying and measuring general classes of man-made pollutants, knowledge and techniques are available for studying almost any situation which has been found to occur. However, in identifying and measuring the individual substances which go to make up these classes, we are not nearly so fortunate. For example, the total amount of solid material in the atmosphere can be measured in any of several ways. But when it comes to measuring certain specific compounds, means of positive identification are still lacking. Even for the partial identification which is now possible, the procedures are tedious and expensive, and only a few laboratories in the country are equipped to undertake such a task.

Most of the measurement techniques for identifying trace quantities were originally developed for industrial hygiene use, where concentrations on the order of a few parts per million were being measured. Now, in studying community air pollution problems, concentrations in the parts per billion range must be measured.

For a large number of substances, methods have been developed to obtain quantitative results from samples taken for periods of 24 hours or longer. For a small number of the more simple gases, such as sulfur dioxide, hydrogen sulfide, and carbon monoxide, methods are available to show the concentration minute by minute. Among the substances which can be measured over longer time intervals, but which we would like to measure minute by minute, are aldehydes, olefins, polynuclear aromatic compounds, and some particular industrial effluents. Since concentration-time relationships are not well understood, studies for a number of different averaging times will have to be made until the relationships become clarified.

Another disadvantage in applying available methods is the matter of cost. Many of the instruments which are now available cost several thousand dollars apiece, which limits their application to situations where the information is urgently needed. Along with the development of new methods of atmospheric measurement, there is great need to make these methods commercially available at lower cost so that they can be more widely applied. Because of the recent history of the development and application of measuring devices, we have become accustomed to thinking in terms of elaborate devices, to the neglect of simple procedures such as impregnated test papers and other straightforward methods. Such techniques as film badges for workers handling radioactive materials, and the indicator crayon used by military forces to measure exposure to toxic gases could be extended to provide techniques for air pollution investigations. These techniques are all averaging techniques; similar methods responsive to peak concentrations are also needed. These might eventually be used in warning systems.

Most of the methods now in use have been adaptations of methods originally developed for other applications, and borrowed for use in air pollution research studies. Incentives need to be provided for the development of methods specific to the needs of air pollution. Special attention is drawn to gas chromatography as a separation technique, supported by infrared absorption and mass spectrography for identification purposes.

Even though our ability to identify and measure pollutants is not as far advanced as we believe it should be, it is much further along than our knowledge of the significance of these measurements as they affect the health and comfort of man.

Where do we stand in our knowledge of the trend

† As presented by Discussion Group Chairmen at the Plenary Session, November 20, 1958.

in change of such pollutants and their pattern of distribution?

The only pollutant for which we have a sufficiently long record of measurement to establish trend is settleable solids. For this pollutant, we know that there was a consistent downward trend for several decades, which has recently flattened out. Sulfur dioxide has been measured for over twenty years in a number of locations, but the results are not available to the public. Fluoride measurements have also been made for over ten years, but the results are likewise unavailable.

Other than these three pollutants, none have been systematically measured for over ten years. The longest record for pollutants, other than fallout, sulfur dioxide and fluorides, is that of the Los Angeles County Air Pollution Control District, where continuous measurement has been made since 1953 of oxidant. Systematic, continuous measurement of carbon monoxide and oxides of nitrogen was started in 1955, when the "alert" system was established.

Analyses of suspended particulate matter by the National Air Sampling Network of the Public Health Service were started on a small scale in 1953; however, for most communities associated with the Network, the starting date is January 1, 1957.

Direct measurements of soiling have been available for several years and are of considerable use in determining progress made in air pollution control.

Thus, it is apparent that long-term trends cannot be established by the data available to the public, for other than settleable solids and soiling index.

A recent survey of the location of continuous, automatic measuring devices for gaseous pollutants showed that 100 of these devices were located in California, 48 were scattered throughout the country in the hands of industrial organizations, and 10 were operated by public agencies outside of the State of California. Thus, it is obvious that data to indicate trends of gaseous pollutants are primarily confined to California. A true national picture of the distribution of suspended particulates has been obtained during the past two years by the National Air Sampling Network. This Network has the limitation of affording only one sampling site in each community, and, therefore, can at best only indicate the general level and type of contamination in the community.

The available measurements of settleable solids and soiling index are primarily from large eastern cities where coal is in widespread use as fuel. Outside of the coal-burning areas, there has not been the public demand for abatement which would lead to the continuous, systematic measurement of gritty and grimy materials in the atmosphere.

The available data show that definite correlations can be established between the type and amount of pollution and such factors as the size of a city, the type of fuel used, types of industry present, common methods of transportation, and other factors related to the patterns of our modern civilization.

Where do we stand in our knowledge of the specific effects of various topographic and meteorological conditions and of concentration or dispersal of sources on the concentrations of such pollutants?

Some knowledge has been available for many years concerning the diffusion phenomena which control the dispersion of pollutants from a point source. Originally developed because of military interest in the spread of a cloud of a toxic agent, this knowledge was later applied to studies of industrial emissions from a single stack. Early in this work, the effects of varying meteorological conditions became evident. One of the most exhaustive studies of pollutants from a point source was completed at Trail, British Columbia, where a complicated meteorological and topographic situation caused widespread pollution throughout an entire valley at certain times. A complete understanding of this situation was necessary before suitable control measures could be developed. The importance of the meteorological phenomenon known as inversion in affecting air pollution situations was first brought to the public's attention as a result of this investigation.

The application of point-source theory to community-wide problems involving multiple sources necessitates a complicated mathematical treatment which is only beginning to be explored. Meteorological measurements at ground level are frequently not sufficient for this purpose, and measurements above ground level are usually even less available. The relationships between meteorology and topography have been under study by meteorologists for many years, and are quite well understood for general flow patterns but not for dispersion of contaminants.

When a combination of unfavorable meteorological and topographic conditions cause air to become stagnant over a community, the possibility is greatly increased that reactions will occur in the atmosphere to produce substances radically different from the materials which were originally emitted. Many of these reactions are not completely understood.

One influence on the concentration of air pollutants may be the dispersal of sources. By applying general principles already known, sources of pollution can often be located relative to pre-

vailing winds and other sources so that adverse effects on the surrounding community can be minimized. In other cases, lack of knowledge concerning a particularly complicated meteorological picture makes proper selection of source location difficult. In still other cases, where winds are extremely light and variable, little can be done from the standpoint of source location.

What, if anything, should be done further on these matters, and by whom?

In identifying and measuring pollutants:

1. Effort needs to be expended in development of refined analytical techniques, to identify and measure pollutants which cannot be adequately measured at the present time in the parts per billion range.
2. More inexpensive methods are needed for continuous monitoring.
3. When monitoring pollutants, peak values as well as average concentrations should be determined until relationships are clarified.

In studying trends in change of pollution levels and their pattern of distribution:

1. Particulate sampling, as is being done by the National Network, should be continued to study long-term trends.
2. Gas sampling should be initiated to study the distribution of gaseous pollutants throughout the nation and to establish long-term trends.
3. A national network based on only one sampling site per community is inadequate to determine the distribution of pollutants within any but the smallest communities. This points up the need for the maintenance of monitoring programs conducted by local communities at sufficient locations to define the local problem. This more intensive local sampling should be conducted in such a manner that results can be compared with other communities and with the National Network results.
4. Much useful information could be obtained with little additional work if the results of previous unpublished sampling could be made available.
5. Monitoring programs should be re-appraised at regular intervals to be sure that they remain dynamic in character and do not become self-perpetuating.

Concerning the effects of meteorology and topography:

1. Existing meteorological knowledge is not being used adequately for the solution of community air pollution problems. Communities should be shown how they can measure and use meteorological data inexpensively and conveniently.
2. Systems of meteorological measurement specific to the needs of air pollution investigations are needed. Most of the present meteorological measurements and observations were established to meet the needs of agriculture, aviation, etc., and do not provide the optimum service to air pollution investigations.
3. Better methods are needed to relate emission concentrations to atmospheric concentration, more particularly for area sources such as cities. Theoretical and experimental studies are urgently required, not only of diffusion at distances of one mile and beyond, but also of the rate of natural cleansing of contaminant gases and particulates from the atmosphere by the processes of washout, rainout, gravitational settling, and turbulent impaction.
4. A better delineation of the air pollution factors responsible for decrease of visibility is needed.
5. There is a need for better and more sensitive tracer techniques, with particular reference to the problems of tracing air movements within an urban area.
6. Recognizing that each community has a limit to the amount of pollution its atmosphere can accept, there is need for more knowledge of the interrelationships between meteorological and topographical factors for the establishment of these limits both for short and long time periods.
7. Atmospheric contaminants such as CO_2 which may be causing long period changes in our climate should be monitored on a national basis at appropriate stations.

In historical perspective, the first measurements of air pollution were supported by local governmental agencies. Industrial organizations responded to these initial efforts by initiating studies in their own laboratories and by supporting studies in educational and research institutions. With the advent of the Los Angeles problem, and the organization of air pollution control there on a county-wide basis, major research support for a considerable period of time became a county responsibility, later to be supported by state-sponsored efforts in California. In recognition of the fact that the problem of air pollution extended beyond the confines of California, federal support of research was sought and initiated. This federally-supportd research has been conducted both directly in federal laboratories, by contract with research organizations, and by grants to individual researchers. A mechanism has also been developed in California through the establishment of a private foundation

whereby funds from industrial sources are made available to support research in private research organizations. It is apparent both that there is no one best agency to support research, and no one best type of research organization to conduct this research. In our future planinng, all methods of obtaining support must be tapped, both private and all levels of government. All available research facilities need to be used in the areas of their greatest competence, depending mainly on where competent individual researchers and suitable facilities are to be found. There is a definite need for recruitment and training of additional qualified persons to meet the challenge of modern air pollution problems.

Dr. Arie J. Haagen-Smit, Chairman
Dr. Herbert C. McKee, Vice-Chairman
Arthur C. Stern, PHS Resource

Group B—Sources of Air Pollution

Our most important program of speakers delivered nine papers, in the course of which various sources of air pollution were discussed; but let us say here that it was not possible, due to shortage of time, to attempt an all-inclusive coverage of possible sources.

As the printed program indicated, the items covered specifically were as follows:

Domestic and Municipal Sources
Industrial Sources, such as:
- Petroleum Refining
- Electric Power Generation
- Metallurgical Processes
- Chemical Processes

Automotive Vehicles

The pollutants which were discussed represented in general the end products of combustion, the products of incomplete combustion, and the emissions of various kinds from process industries. Where quantities of pollutants were known or available, they were reported by the authors, and it is unnecessary to repeat this information here. However, it was discovered that information on the types as well as the quantities of pollutants was not known for all sources, and that many gaps in this information exist largely because of the lack of analytical and test procedures. The panel dealt principally with primary sources of pollution, but it was recognized that secondary pollutants may result from reactions in the atmosphere.

Information on the quantities and types of emissions is basic to the problem of control. This information establishes quantitative objectives for control and identifies substances which are known to affect health, damage property, or create nuisance.

In any locality, the significance of any single pollutant or group of pollutants will depend upon the amount, the topography, the meteorology, and the number of sources involved, as well as the density of the population in the vicinity. Each community is a specialized problem and the pollutants which may be of concern to one geographical area will not necessarily be a problem to another.

There is a need for determining the relationship between the emission rate of a specific pollutant and its effect on the environment. It is desirable to establish tolerance thresholds with respect to effects on health, growing plants and animals, and the creation of nuisances.

The history of technology suggests very strongly that patterns of emission from all sources will change in the future. An example of this is the substitution of nuclear energy for fossil fuels in the production of power. Similarly, technological development continually alters the types of emissions from chemical processing and manufacturing. The precise direction in which these changes will occur cannot be predicted, but the fact that they will occur is certain, emphasizing the need for continuing source appraisals.

The rapid development of urban areas makes the significance of future increases in pollutants particularly important since greater numbers of persons will be exposed to the effluents from these sources.

The opinion was expressed by many speakers that neither knowledge of types of pollutants at their sources nor present methods of analysis is adequate. It was pointed out that in some areas the methods of identifying pollutants are not specific enough. Furthermore, in certain cases where methods are known, they are either too expensive or too time-consuming, or both, and adequate methods for identifying minute quantities of pollutants are not readily available. We believe that there exists a need for knowledge and information on more specific, accurate, less time-consuming and less expensive methods for evaluating pollution sources.

In addition, there exists a need for a systematic compilation of available information on emissions from all sources, as well as a means for improved communication and dissemination of this information as it is developed.

We do not believe that the development of these improvements is the sole responsibility of any one agency, group, or individual, but that what is needed is the coordination of the efforts of all groups who are interested in this problem. By this we mean that industry and manufacturers of equipment have a responsibility for establishing information on emissions from their processes

and devices; that research organizations should be encouraged to contribute significantly in this field; and that communities should develop information relative to their pollutant sources.

There is a need to make generally available information on sources of pollution and to analyze these data in order to avoid unnecessary duplication and to serve as a guide to others investigating these and related problems. In this regard we believe that it is necessary and proper that the activities of the Public Health Service in the dissemination of this type of information be expanded and continued on a permanent basis.

It is the consensus of our Group that no time should be lost in carrying out the suggestions made herein. The rapid growth of the population and of the national economy, and the attendant increase in the quantities of pollution from all sources indicates the need for immediate action.

In conclusion, members of Group B recommend that the Public Health Service implement the following program at the earliest possible date:

1. Intensive development of instrumentation for source analysis.
2. The provision for training of specialized personnel in source studies.
3. The encouragement of communities to assess continually the sources of pollution within their boundaries, with technical assistance from the Public Health Service if requested.
4. The systematic collection, analysis and dissemination of information on emissions from all sources in cooperation with local communities.

Sylvan L. Hanauer, Chairman
Dr. Leslie A. Chambers, Vice-Chairman
Dr. August T. Rossano, PHS Resource

Group C—Health Effects of Air Pollution

Concern about the actual and potential threat to health of atmospheric pollution has run through most of this Conference. Several aspects of the health problem were noted by Dr. Burney in his opening remarks. Further references were made in various ways by Dr. Hilleboe, by Senator Kuchel and by Dr. Leake in their remarks at the opening session. In his discussion of *What does air pollution do to humans?* Dr. Dixon summarized the current knowledge of the relation of atmospheric pollution to health.

From this general overview, Group C probed somewhat deeper into the problem. Our 200 participatants devoted the four-hour morning session to look at general and several specific aspects of the health effects of air pollution.

Mentioned in the first plenary session were several acute air pollution episodes. Our group analyzed in somewhat more detail these acute episodes and lessons to be learned from them. In medicine we often refer to subclinical disease. Along with the specific Donora and London episodes, consideration was given to other incidents that approached the level of clinical recognition.

In future years such events may well be recognized as acute episodes of lesser intensity when our observation acumen is sufficiently sharpened. Possible approaches to more scientifically and accurately studying these incidents were noted.

Also mentioned to you were possible chronic disease entities that might be attributed to long time and repeated exposure to low concentrations of air pollutants. Group C paid particular attention to this matter. Laborious epidemiologic studies were described which are essential to the elucidation of the role of polluted air in the causation of chronic diseases. Particular attention was paid to chronic bronchitis, asthma, emphysema, cardiac and circulatory diseases, and to cancer. There was some probing into the intricacies of the anatomical and physiological changes in the lungs and other organ systems resulting from exposure to atmospheric pollutants.

From this four-hour session a number of generalizations seemed to come forth to those of us who participated. Much knowledge about the medical effects of polluted air is already available. Many potentially important and significant leads have been uncovered. The body of knowledge is increasing in many directions and at an accelerating rate. I, for one, was heartened by the evidence of progress. I'm sure that as each of you studies the reports we heard yesterday, you also will catch a glimpse of the horizons ahead through the gradually dissipating smog of the unknowns.

In the afternoon, Group C divided into six discussion groups. The objective was for each group to consider specific questions that had been propounded by the Inquiries Committee. It was understood that the groups could go beyond the specific questions. At the end of the afternoon we reassembled and listened to the reports from each of the six groups.

In the time available, I cannot give you their complete reports but will attempt to summarize the conclusions and recommendations. There were several general recommendations that came in one form or another from several of the groups:

1. There seemed no question that the national Air Pollution Program should be continued and expanded.
2. In the continuance of the program it was emphasized that problems in air pollution will be with us indefinitely, so the specific enabling law should have no specified ter-

minal date. As one group stated, there should be "permanent extension of Public Law 159."

3. It was recommended that placing a legal ceiling on appropriations was unrealistic; budgets should be considered annually by the Congress on a basis of current program needs and potential for effectively utilizing the funds.
4. It was concluded that since there are many unanswered health questions there should be acceleration of research on the health effects of air pollution. In such an accelerated program there should be participation by all agencies such as official health agencies, research organizations, universities and industries, including the automobile industry.

   In this regard it was emphasized that there are existing research potentials that, for lack of funds, are not being utilized.
5. It was recognized that intensification of control efforts should not and cannot await the definitive answers to many of the medical problems. However, there was agreement that it is imperative that such answers be found at the earliest possible time since they will serve to better guide the development and design of control programs.
6. From one group came agreement that nuisance due to air pollution should be regarded as a public health problem. Among the reasons noted were the effects upon efficiency and upon emotional and physical comfort and well being. It was felt these effects need not necessarily be manifestations of specific disease entities.
7. One group specifically considered the responsibility of the voluntary health agency in the air pollution field. In summary, it was concluded that such agencies should participate in promoting air pollution control, in promoting and sponsoring health research, in supporting official agencies and in an educational capacity.
8. Another group paid particular attention to to the responsibility of practicing physicians and recommended that: First, organized medicine, through national, State, and local medical societies, should collect and disseminate air pollution information to its membership; second, that the proceedings of this Conference be made available to physicians and public health authorities; third, that private physicians individually should be encouraged to use local facilities and services, such as those of local health departments or air pollution control authorities, to assist them in the management of clinical problems that may involve air pollution. Physicians should also serve as interpreters of the health aspects of the problem to their patients and to others in the community.
9. The question of *How would you estimate the impact of air pollution on your community health?* was considered by another group. Mentioned were eye irritation, irritation to the respiratory tract and upon emotional well-being, including anxiety about the possible hazard to health. They noted that because of incomplete information on the health effects of air pollution, community hysteria may develop which, among other things, may lead to unnecessarily restrictive laws.
10. Still another group considered the question of *What should be the responsibility of government—federal, state and local—in the determination of the health effects of air pollution.* It was concluded that the current plan of cooperation among the three levels of government is effective and should be continued. In this instance I should like to quote the complete statement of the sub-group: "There was general consensus that grossly inadequate information on health effects of air pollution was available upon which to base sound, nondiscriminatory legislation to effectuate control."

    In discussing the role of government, there was no intent to imply that the responsibility was government's alone, but that, indirectly, research groups, academic institutions, as well as other groups, do have a share in the responsibility of determining the health effects of air pollution.

There was developed a set of recommendations designed to offset the lack of information on health effects and to delineate major responsibilities of the several levels of government:

1. In general, air pollution problems common to the country as a whole should be the responsibility of governmental agencies at all levels.
2. Problems more local in nature should be the primary responsibility of the pertinent area, but consultative advice and guidance should be available and sought from state and federal agencies.
3. Emphasis was given to an integrated team approach to the determination of the health effects of air pollution to provide efficient correlative data. Such a team approach would entail the collection of concurrent medical, epidemiologic, and aerometric data.
4. It was felt that local resources were not be-

ing utilized adequately and that additional useful medical statistics could be secured within the framework of well organized data collection programs involving the local health resources and facilities, such as health departments, registrars of vital statistics, practicing physicians and hospitals.

5. Although more could be done with existing facilities, it was felt that an adequate program at the local level in most instances would require augmented financial support and intensive stimulation of interest.
6. As such significant health effects data become available, every effort should be made by the federal agencies to disseminate such information to the states and, similarly, by states to local agencies.
7. Since adequate methodology in determination of health effects and sufficient competent personnel were not yet available, it was felt that a crash program for definition of health effects was certainly not indicated at this time. In this regard, there should be promoted, instead, an orderly but aggressive program of research in this area.

Dr. Malcolm H. Merrill, Chairman
Dr. James P. Dixon, Vice-Chairman
Dr. Harry Heimann, PHS Resource

Group D—Economic and Social Effects of Air Pollution

Education: We recommend a continuing and intensified education program in the following four areas:

1. The education of personnel so that the problems of the future can be met and solved.
2. The education of industry by the dissemination of existing information of industry's obligation for air pollution abatement.
3. The education and assistance for public officials in meeting local problems of air pollution.
4. The education of the general public in its obligations of controlling their own contribution to air pollution problems.

Research: The following areas need study:

1. The effect of air pollution upon organisms and materials.
2. Extent and cost of air pollution on our economy and society.
3. Extent and cost of air pollution control on our economy and society.
4. Research into administration and legal techniques of air pollution control.
5. Research on sociological implications of air pollution and air pollution abatement.
6. Research and development of new and less costly air pollution control techniques.
7. The encouragement of research in by-products and development investigations.

Action: The Group recommended:

1. The continuation and expansion of Public Law 159.
2. The creation of a stronger liaison between government and the general public and the establishment of a liaison between government and industry. (With these efforts toward better liaison, we will have an understanding of the meaning of our living together in a cooperative effort.)
3. Governmental cooperation with local organizations in the development of programs and effective measures which will further effective and fair air pollution control measures.
4. Machinery to be set up to promote periodic national meetings for the comparison and evaluation of air pollution control progress.

Dr. Christopher E. Barthel, Jr., Chairman
Arthur Crago, Vice-Chairman
Dr. C. Stafford Brandt, PHS Resource

Group E—Control Methods and Procedures for Air Pollution

Summary: During the past decade, substantial progress has been made in the basic knowledge and in the technology and practice of air pollution control. Industry and government both have contributed to this progress. Industry is spending millions of dollars a year in research and hundreds of millions a year in control of air pollution. Government and nonprofit agencies are also spending large sums of money for similar purposes. These expenditures have resulted in substantial improvement.

Scientific, engineering and trade associations have held numerous conferences on air pollution in recent years. Their publications have presented useful scientific and engineering developments. These publications have promoted wide application of the new knowledge, particularly in larger installations, but more effective use of the present knowledge can be made.

The means are presently available for adequate removal of many pollutants within cost limits which are economically feasible. Such means are not available for certain other pollutants, but in many of those cases removal is desirable but not essential. The economic justification depends on the conditions which exist in each instance. For many of those pollutants for which the need of control has been most urgent and widespread, economical methods for correction have been developed. In certain industrial applications the control cost results in a direct charge to the local industry which, in turn, passes this cost as an increase in consumer cost to the local community

benefiting from the application of control; in others, it results in a customer cost which is borne nationally. In the case of municipal and domestic sources, the direct cost of control is borne by the community.

It is recognized that a public awareness should be directed to the value of industry standards and principles applicable specifically to new installations having a significant air pollution potential for the purpose of minimizing the development of new air pollution problems in the future.

Recommendations:

1. The Committee recommends that it be a joint responsibility of government and industry to sponsor and conduct research on air pollution control. It is recognized that industry welcomes government support of research as a means of identifying, defining, and developing approaches to solutions. The responsibility for the solution of specific problems associated with a specific industry or plant lies with that industry.
2. Further research and development should be implemented to expedite controlling emissions from high temperature combustion and metallurgical operations.
3. Further studies must be undertaken to develop economic means for the removal of low concentrations of gaseous pollutants such as oxides of sulfur and nitrogen from combustion gases for application in areas where these may be a problem.
4. We urge that the education and training of engineers in the field of air pollution control should be continued and if possible expanded.
5. Recognition should be accorded to the importance of developing economical survey techniques that can quantitatively define the relative importance of the application of control equipment in a community.
6. Properly designed and engineered control equipment should be incorporated in the initial plant specifications. Codes for guidance in this practice should be developed by voluntary industry groups and engineering societies. Support for this endeavor should be encouraged.
7. In regard to automobile exhaust emissions, the following recommendations are made:
   (A) Work on the development of analytical techniques and instrumentation and studies of exhaust gas composition should be continued by both industrial and governmental agencies.
   (B) Those industries presently engaged in developing exhaust system control devices should continue their work at a vigorous rate.
   (C) The automobile industry should continue its study of the maintenance aspects of the automobile exhaust air pollution problem.
8. Research agencies should continue their program on the health aspects of all air pollutants in order to expedite the development and application of control methods.
9. The study of atmospheric reactions should be continued so that as control methods become available those urban areas affected with an air pollution problem can determine whether or not the application of such control methods will be effective in their particular problem.

Dr. Leslie Silverman, Chairman
Wesley C. L. Hemeon, Vice-Chairman
Andrew H. Rose, Jr., PHS Resource

Group F—Administrative Aspects of Air Pollution

What are the respective responsibilities of the individual, business and industrial activities, and public agencies in the prevention and control of air pollution?

The control of air pollution requires the co-operation of the whole community. While an industrial source may contribute more than an individual, it should be recognized that the total contribution to the air pollution load by individuals may equal or exceed that of industry. The individual has responsibility to prevent or reduce air pollution resulting from open fires, trash incineration, home heating plants, and improper functioning of his automobile within the technological limits which exist at the time.

As an integral and vital component of the community, business and industry have a responsibility in the prevention and control of air pollution as a good neighbor and for the general welfare of the community. In this regard, it is incumbent upon them to recognize that air is a limited natural resource. The use of the air is common to all, and neither public use nor custom grant special consideration to any components of the community.

Local public agencies have responsibility for dealing with the air pollution problem through several approaches. First, the community must take initiative in providing services for the collection and disposal of refuse in a manner which will not pollute the air. Second, the public agencies should conduct their operations in an exemplary manner to avoid pollution of the air. Finally, that local or regional public agency, capable of dealing with the air pollution problems

in the area, should be given the responsibility for the conduct of a control program. This intends that recognition be given to those factors common to such an area because of topography, meteorology, sources of pollutants, and effects.

The appropriate state agencies should assume responsibility for leadership, technical assistance, and guidance to the local control agencies. In this manner, the state can function effectively by assisting local agencies in appraising their air pollution problems and providing necessary technical assistance. The state agency should also maintain a continuing program of study and appraisal of air pollution levels throughout the state. The state should encourage local control legislation and local control operation, where feasible, but the state should assume the responsibility for control in all those areas where the organization of local or regional programs is not feasible, or where a local control program is needed and has not been established.

The most effective manner in which to assess relative responsibilities in a community would be by means of preliminary study and appraisal of the air pollution problems. This should be followed by a determination of responsibilities in a cooperative manner, recognizing the equities involved.

The role and responsibility of the Federal Government is clearly expressed in Public Law 159 of the 84th Congress. This Act provides for the conduct by the Public Health Service of a program of research, technical assistance, and training. This law was enacted in 1955 and provided for an initial period of five years of federal activity in this field with the intent of reappraising the problems and needs at the end of that time. Although much needed research results have been achieved, it is not possible to accomplish the objectives of the Act within the five-year period. For example, the effects of air pollution on health and the control of automotive exhaust gases are but two of the many vital problems on which further work needs to be done. In the public interest there is continuing need for research which can best be conducted by the Federal Government. The nation-wide importance of air pollution problems indicates the real need for amending Public Law 159 to extend the authorization for the program.

The Congress in enacting Public Law 159 also included a provision limiting the annual appropriation to a maximum of $5 million. Air pollution research includes many complex aspects involving study over an extended period of time, particularly those concerned with the chronic health effects. This fact, together with the possibility of an engineering or medical research "breakthrough" which might make desirable an expansion of activities for further development and exploitation, suggests that no appropriation limitation should be included in the extension of the Act. The annual budget review and appropriation procedure provide adequate financial control. The air pollution problems of our country are so vast in scope and, if unchecked, will without doubt increase in severity due to the rapid increases in industrialization and urbanization which are taking place; therefore, we feel it is undesirable that a ceiling be placed on the funds authorized by the Congress for work by the Federal Government in this field.

In general, in the conduct of air pollution control programs should air pollution control be organized on a local basis? Regional? State? Other?

Public Law 159 specifically declares it to be the policy of Congress to preserve and protect the primary responsibilities and rights of the states and local governments in controlling air pollution. This policy declaration is clearly in harmony with the Federal Constitution under which the police powers, with certain exceptions, are reserved to the respective states. Thus, the control of air pollution, as an exercise of the police power, is a responsibility primarily of the states and, to the extent delegated by them, to their political subdivisions.

In many cases, air pollution can be dealt with by a single local political subdivision. Air pollution, however, frequently does not respect political jurisdiction and consequently many communities are unable to deal effectively with this problem on an individual basis. Experience, thus far, clearly indicates the desirability of meeting the air pollution problem on a problem-area basis. This would involve, as the case may be, purely local or regional efforts, the latter by interlocal or interstate cooperation. As one practical approach, the Council of State Governments has suggested state enactment authorizing co-operative activities between local subdivisions on a joint basis. The act would permit the exercise of power already possessed by a political subdivision in conjunction with one or more communities for a common end. It should be noted that the suggested act is drafted for use between or among communities whether or not they are located within a single state.

There are some situations which are primarily regional and dependent upon a number of common factors, such as weather, topography, population concentration, and industrial development, among others. A number of state legislatures have recognized this need and have enacted ap-

propriate enabling legislation. In the control of air pollution, it is clear that the functions of the states lie in two general categories: (1) those concerned with the legal delegation of appropriate powers to their political subdivisions or groupings of them, and (2) those concerned with the direct activities of the state government itself. For the first, state initative and action is a necessary antecedent to effective local or regional activities. In addition, there is need to encourage cooperation and coordination between states in dealing with interstate air pollution problems. The Federal Government in the exercise of its jurisdiction over commerce on navigable waters should delegate authority for control of air pollution to the states.

What relative emphasis should be placed on education, voluntary action, regulation, legal enforcement?

The active cooperation of the various components of the community is most desirable and essential for a successful air pollution program. There is also the necessity of achieving a proper balance among the elements of a community air pollution program, appropriately tailored, which would include among others, education, cooperation, regulations, and legal enforcement. Education of all concerned plays an important role in securing understanding and cooperation. It provides the means of describing the problem, needs of the community and what can be done.

The rules and regulations establish the objectives. The promulgation of such rules and regulations performs the significant function of guidance and provides a uniform approach, where applicable, to the air pollution problem. Obviously, for the recalcitrant few, there is need to resort to legal remedies. The legislation must be reasonable and just, based upon a sound technical foundation.

What is the role of the zoning in air pollution control

At the present time, satisfactory acceptable variations in standards of air pollution control relating to zoning and planning have not been evolved. It is recommended that planning and zoning experts, working together with air pollution officials, devote further study and research to this problem.

How should air pollution control be paid for?

This question involves two aspects: first, that involving the cost of operating the control agency; and second, the cost of providing and operating processes or equipment for actually preventing or controlling air pollution.

All segments of the community are concerned with the control of air pollution and many of them are affected by the financial equities involved. The official control actions, undertaken in the over-all public interest, should be supported therefore by public funds. This may be tempered by an appropriate system of equitable fees covering the cost of special services rendered by the official agency to individuals or business and industrial organizations.

On the other hand, every individual or organization must be expected to defray the cost of necessary steps in preventing or controlling air pollution which would otherwise result from activities carried on or controlled by him.

Dr. Louis C. McCabe, Chairman
Harold W. Kennedy, Vice-Chairman
Samuel M. Rogers, PHS Resource

Noise Rise Calculator

A NEW SLIDE RULE calculator by which room noise rise may be predicted using fan "sone" ratings has been developed by the Propellair Division of Robbins & Myers, Inc. U. S. fan manufacturers have been among the first to switch from decibel to sone ratings, which are now given in their catalogs. Using this data and the characteristics of any room, the probable noise rise from the installation of one or more fans can be calculated. Normally, two settings are required. The calculator can also be used for other equipment having a noise spectrum similar to that of most rooms and a known sone rating. Calculators are available at no charge when requested of the Propelair Division, Robbins & Myers, Inc., Springfield, Ohio, on your company letterhead.

News of Local Sections

Chicago

In December, the Chicago Section joined in a social evening and dinner with the ASSE. Wives were invited and the evening was a complete success with professional entertainers and door prizes.

W. C. McCrone, Ph.D., the head of his own company in Chicago for research in microchemical analysis and air pollution, spoke at the January meeting on "Uses of the Chemical Microscope in the Study of Industrial Hygiene and Air Pollution." With the aid of slides, he showed how valuable microscopy can be for the identification of many particulate components.

A visit to the Argonne National Laboratory was featured for February. Over 100 members showed up and were escorted in groups through the many laboratories. The occasion was complete with cocktails and dinner.

Digressing from the strict field of industrial hygiene, the March meeting offered Mr. J. C. Staehle, Vice-President, Alden's Inc., speaking on "Have You What It Takes to Succeed?" A chief point of his talk was "Do not be afraid to be a non-conformist."

Officers elected for 1959–1960 are: President, Paul D. Halley, Standard Oil of Indiana; President-Elect, George P. Bittner, Inland Steel Company; Secretary-Treasurer, Anthony Woewucki, Jr., Continental Casualty Company; Directors for three years, Stephany Augustyniak, R.N., Johns-Manville Company, James L. Kennedy, Portland Cement Association, Thomas J. Mackey, Karel First Aid Supply, and Frank J. Wagner, Deere and Company.

New Jersey

Wally's Tavern on the Hill, Scotch Plains, New Jersey was the sight of a social meeting for the section in January. Fifty-two members and a special guest, President Ken Nelson, made the evening gay and memorable.

Tennessee Valley

The fall meeting was held at Oak Ridge on December 15. Fifty-six stalwarts registered for this all-day meeting at which eight papers were presented and discussed. In the business session the following officers were elected: President, Harold J. McAlduff, U. S. Atomic Energy Commission; President-Elect, Frank L. Goddard, Tennessee Eastman Corporation; Secretary-Treasurer, R. B. L. Fleming, Tennessee Valley Authority; Local Section Council, J. G. Morehead, Union Carbide Nuclear Company; and Director for three years, Frank Cox, Aluminum Company of America.

Western New York

The section has had a very successful season during which membership increased steadily. A symposium on heat in industry was held and talks were presented by the following: Franklin A. Miller, Richard F. Scherberger, Herbert I. Miller, J. B. Moses, M.D., Karl L. Dunn, William A. Miller, Fred Prince, and Rev. James J. Ruddick, S.J. After cocktails and dinner, Norman P. Robie spoke on "A Century of Fantastic Inventions."

On December 8, 1958, a joint dinner meeting with the Genesee Valley Chapter of the American Society of Safety Engineers was held. The speaker was Robert L. Young, Noise Analyst for Employers' Mutuals of Wausau, and his topic was "Prevention of Hearing Loss from Industrial Noise."

Metropolitan New York

Hanson Blatz has resigned as Chief of the Radiation Branch, AEC Health and Safety Laboratory to accept the appointments as Radiation Consultant to the City of New York and Associate Professor of Industrial Medicine at N.Y.U. Bellevue Post-Graduate Medical Center.